OUR HUMAN STORY: AN INTRODUCTION TO BIOLOGICAL ANTHROPOLOGY



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Our Human Story: Introduction to Biological Anthropology

An OER Text by Rachel Mitchell

Gavilan College

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About This Text

Acknowledgements

This Open Educational Resource (OER) text was made possible by a grant from Gavilan College as part of an Academic Senate for California Community Colleges (ASCCC) funded initiative supporting the creation of Zero Text Cost (ZTC) textbooks to reduce the costs of, and barriers to, higher education for college students.

I am deeply grateful to the OER/ZTC Project Leads, Dr. Deborah Gustlin and Dr. Debra Klein for their support, enthusiasm, guidance, and encouragement. Many thanks also go to my anthropology colleagues at Gavilan College, Dr. Debra Klein, Dr. Gina Michaels, and Dr. Gary Velasco, for their camaraderie during this year-long, program-wide project and professional learning journey.

Introduction

A central question in anthropology is: *What makes us human?* Biological anthropology attempts to answer this question by placing humans in a broad biological context so that we can see how we are shaped by the same natural, biological, and genetic processes as all living beings. How are humans both similar to yet distinct as a biological species? And how has biology and culture shaped our human story through time?

This text aims to help students address these and other questions, drawing on anthropological and evolutionary perspectives on important developments in our evolutionary history, while encouraging ongoing exploration and reflection on what it means to be human upon the earth.

How To Use This Book

The vast majority of content in this book was derived and adapted from other Open Educational Resources, each of which is acknowledged at the end of the section page or at the conclusion of each chapter in the References and Attributions. Original content included in each chapter reflects my own personal and professional interests as a lifelong learner and student of anthropology, including interesting “Did You Know?” features. It is my hope that some of the topics and issues presented there will invite curiosity and serve as starting points for further research.

As an introductory text, this book’s content and style are intentionally designed to be accessible for early undergraduate learners just encountering the discipline of anthropology—and the specific subfield of biological anthropology, which draws on a number of highly specialized scientific disciplines, including genetics, primatology, osteology, and paleoanthropology, to help piece together the puzzle of our human story. Many other OER texts consider the contributions from these fields in much greater depth and detail, and I encourage readers to consult these sources if they feel they need more substantial treatment of this particular material. For the purpose of this text, much of this material has been distilled to provide foundational context without overwhelming students with too much technical terminology, while maintaining scientific accuracy.

Additionally, I have attempted to keep references and citations to a minimum, both to support an accessible, generalized reading experience and to help readers grasp key concepts of the text without extensive distraction. Bibliographies are included at the close of each chapter to give educators and learners resources for further exploration.

AI Tools Used in the Production of This Text

In the interest of transparency, I want to share how AI tools were used in producing this text. I used Anthropic’s Claude to: 1) edit and condense long passages, including breaking reading sections into smaller chunks and suggesting and refining heading titles; 2) research topics I already have background knowledge in, as a way of assessing the reliability and currency of the sources it provided; and 3) generate alternative text descriptions for some of the images. I also used Google Gemini to produce some content-specific images as visual aids for illustrating key concepts or information. These are clearly labeled where they appear.

I’m mindful of the costs and limitations of AI, and have used these tools deliberately, mainly as an opportunity to develop my own

AI literacy, which is increasingly relevant for educators today. I felt it was important to acknowledge exactly where and how these tools shaped this text.

Dedication

This text is first and foremost dedicated to all students of anthropology.

It is also dedicated in memory of Ricky, the sweet kitty who sat in my lap, by my side, or even right on my notebooks as I worked on major portions of this text. He remains always close to my heart.



Figure 1: Ricky, the British "Blue" Shorthair, and the author's "grandkitty."

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1.1: Introduction to Anthropology

Introduction to Anthropology

Anthropology is the study of what it means to be human. If you've ever scrolled through social media wondering why different friend groups have their own inside jokes and communication styles, or questioned why your family's holiday traditions differ from your roommate's, you're already thinking like an anthropologist.

Anthropologists make strange things familiar and find the strange in familiar things. Ever wonder why TikTok trends spread so quickly across cultures? Why dating apps have transformed how people meet and form relationships? Or how remote work is reshaping our sense of community? These are all anthropological questions.

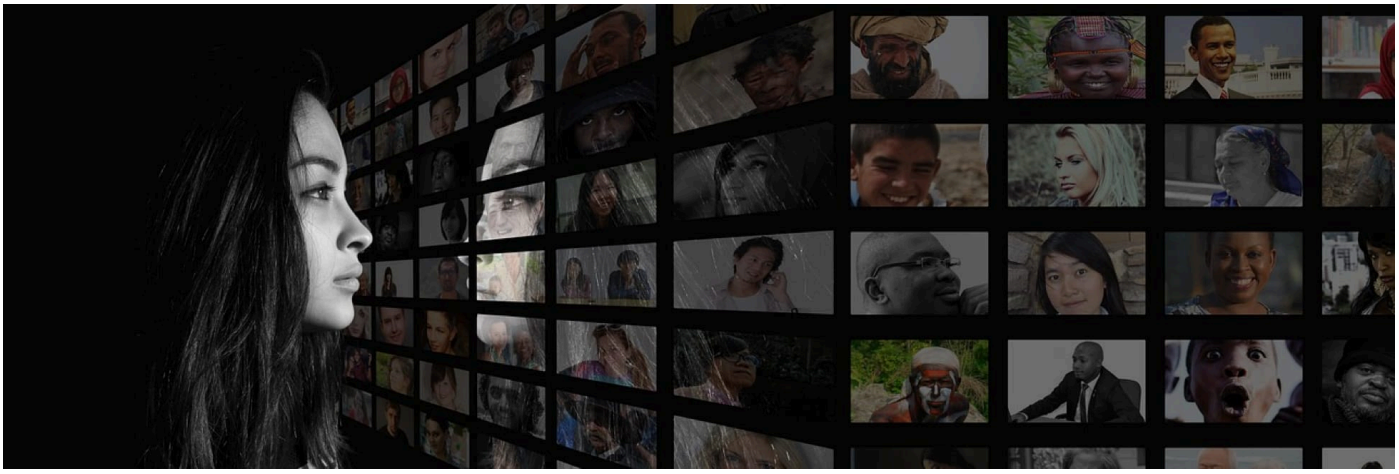


Figure 1.1.1: Facing the diversity of humans. Image by Gerd Altmann from Pixabay

What Makes Anthropology Different from Other Social Sciences?

Anthropology stands out because of *how* anthropologists study human life and culture. They use **holistic**, **comparative**, and **relative** approaches to understand the incredible diversity of human experience. For example, an anthropologist might study how Gen Z activists use social media to organize climate protests, how gaming communities develop their own languages and social hierarchies, or how pandemic lockdowns transformed family dynamics across different cultures. Others might investigate how ancient humans adapted to climate change, or use forensic methods to identify victims of mass violence and bring closure to families.

The Four (or Five) Fields

Because humanity is so complex, anthropology is typically divided into four main fields: **cultural**, **linguistic**, **archaeology**, and **biological**. Most anthropologists specialize in one or two areas, though these fields constantly overlap. Some researchers also identify a fifth field: **applied anthropology**, which focuses on using anthropological insights to solve real-world problems.

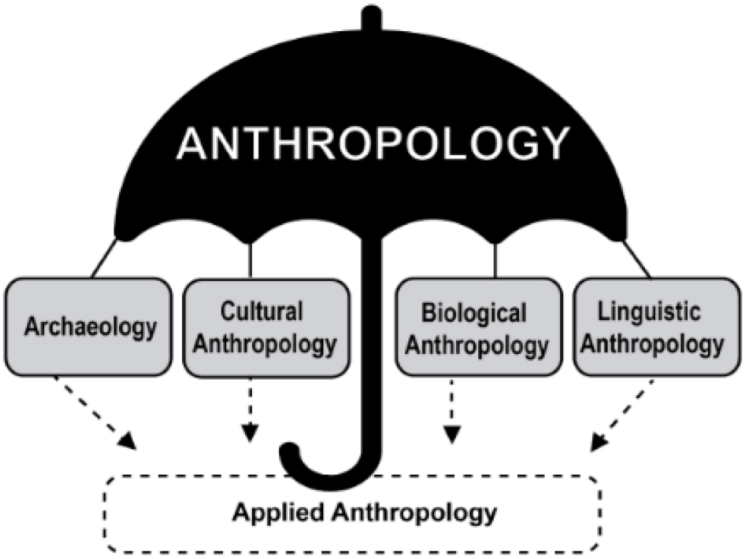


Figure 1.1.2: The discipline of anthropology has four subdisciplines: archaeology, cultural anthropology, biological anthropology, and linguistic anthropology, as well as an applied dimension. Credit: Subdisciplines of anthropology (Figure 1.8) original to Explorations: An Open Invitation to Biological Anthropology by Mary Nelson is under a CC BY-NC 4.0 License.

These divisions help manage the massive scope of human experience, but they don't exist in isolation. Anthropological research often crosses boundaries because understanding humanity requires a **holistic** approach—like understanding how all the pieces of a puzzle fit together to create the complete picture.

Cultural and linguistic anthropology focus on behavior and communication, exploring how we create meaning and share it with others. **Archaeology and biological anthropology** emphasize the material world—our bodies, the objects we create, and the physical evidence we leave behind.

Cultural Anthropology: Understanding How We Live Now

Cultural anthropologists work with living communities to understand how cultures form and change. They might explore how immigrant families navigate between their culture of origin and their new home, how online communities develop shared identities and norms, or how social movements like Black Lives Matter or #MeToo reshape cultural conversations about equality and justice.



Figure 1.1.3:Women's March in Oslo, Norway, part of the #MeToo Movement. Image by GGAADD, CC BY-SA 2.0 via Wikimedia Commons

The primary method used by cultural anthropologists is **participant observation.** Anthropologists immerse themselves in communities, participating in daily life while carefully observing and documenting what they see. This might mean attending protest marches, joining Discord servers, working alongside farmworkers, or living in rural villages. They conduct interviews, take field notes, and often use surveys or statistical analysis to complement their observations. This fieldwork results in **ethnographies**—rich, detailed accounts of how specific groups of people live and make meaning in their worlds.

Recent ethnographic studies have explored topics like how healthcare workers coped during the COVID-19 pandemic (Singer & Rylko-Bauer 2021), how students experience mental health on college campuses (Wilson 2023) how food delivery workers navigate gig economy platforms (Ravenelle 2019; Woodcock 2021), and how communities across the globe rebuild after natural disasters such as fires, floods, hurricanes, or earthquakes (Azadegan 2018). Cultural anthropologists help bridge understanding between different groups and remind us that beneath surface differences, humans share fundamental needs, desires, and capacities.

While many work in universities, applied cultural anthropologists also work with non-governmental organizations (NGOs), tech companies (studying user experience and digital culture), public health organizations, and social justice initiatives.

Linguistic Anthropology: The Power of Words

Linguistic anthropologists study how language shapes and is shaped by culture, history, and biology. They explore everything from how new slang emerges and spreads, to how multilingual individuals shift between languages in different contexts, to what happens to languages when they're endangered or going extinct.

Think about how many words exist for being online: scrolling, lurking, doomscrolling, going down a rabbit hole, being chronically online. A linguistic anthropologist might ask: what do these terms tell us about our relationship with technology? (Gershon 2010; Miller, et. Al. 2016). Or consider how the same word can carry different meanings across generations—"slay," "ghost," "lit." Linguistic anthropologists examine not just spoken words but also emojis, memes, gesture, body language, and even silence.

Recent research has explored how social media is creating new dialects, how **code-switching** works in multicultural workplaces, how gender-inclusive language is evolving, and how accent and speech patterns can affect everything from job interviews to court proceedings.



Figure 1.1.4: Two women chat during an interview. Photo by Christina @ wocintechchat.com M on Unsplash

Archaeology: Decoding the Past

Archaeologists study human history—from our earliest ancestors millions of years ago to events that happened last week. They excavate sites to recover **artifacts** (objects made or used by people) like pottery, tools, building foundations, or even 20th-century landfills to understand what people bought, used or consumed, and threw away.

Through these objects, archaeologists reconstruct how people lived: what they ate, how they organized their societies, who they traded with, what they believed in. They might map ancient cities, analyze residue on cooking pots, or use satellite imagery to discover hidden structures. Today, most archaeologists work in **cultural resource management**, ensuring that construction projects don't destroy important archaeological sites (King 2020; Welker 2024).



Figure 1.1.5: Archaeologist Ben Diaz works on a root in one of two different sites in the Ohanapecosh campground. NPS photo by Emily Brouwer. Mount Rainier National Park from Ashford, WA, United States, CC BY 2.0 via Wikimedia Commons

Modern archaeology is increasingly collaborative, working with indigenous descendent communities to interpret findings. For instance, archaeologists studying Indigenous sites now often partner with tribal nations to ensure respectful, accurate interpretation. Recent archaeological work has revealed everything from medieval pandemics to Cold War nuclear test sites to the material culture of enslaved peoples in the Americas.

Biological Anthropology: Studying Adaptation and Change in Humans Over Time

Biological anthropologists study how humans and our primate relatives adapt to different environments, how we evolved, and how biology and culture interact. They might study skeletal remains, analyze ancient DNA, observe living primates in the wild, or investigate how human bodies respond to everything from high altitude to new diseases.

Primatologists study living apes, monkeys, and other primates to understand the evolutionary roots of human behavior—everything from tool use to social cooperation to conflict resolution. **Paleoanthropologists** study fossils of early human ancestors to trace how we evolved over millions of years.

Applied biological anthropology includes **forensic anthropology**, where experts help identify human remains in criminal cases or mass disasters, and **medical anthropology**, which examines how culture, economics, and politics shape health outcomes (Steadman, D. W. 2016; Gamlin, et. al 2021; Hahn & Schoch-Spana 2021). Why do some communities have higher rates of certain diseases? How do cultural beliefs affect whether people trust medical treatments? How did COVID-19 impact different populations unequally? These are medical anthropology questions.

The Comparative and Applied Approach

All anthropological fields use a comparative approach—examining multiple groups, time periods, or situations to understand patterns and variations in human experience. You can't understand what makes a culture unique without comparing it to others just as you can't fully grasp modern social issues without historical context.

Many anthropologists also do **applied anthropology**—using anthropological insights to address real-world challenges. Applied anthropologists work in diverse settings: tech companies studying user behavior, hospitals improving patient care, government

agencies shaping policy, museums creating exhibitions, NGOs addressing poverty or human rights issues, and corporations navigating cross-cultural business practices.

According to the American Anthropological Association, more than half of anthropologists work in applied settings. An anthropology degree develops skills that are valuable everywhere: critical thinking, cultural competency, research and analysis, communication across differences, and the ability to see familiar things from new perspectives.

NON-PROFIT PROFILE: GRAVITY WATER - Applying Anthropology to Help Solve the Global Water Crisis

Gravity Water is a Santa Cruz, California based nonprofit with a mission to empower communities with sustainable water solutions across the globe. Founder and Executive Director Danny Wright credits a community college cultural anthropology class with shaping his approach to working collaboratively with community leaders to develop the infrastructure needed to help bring clean drinking water to schools and communities facing water scarcity. Recognizing the need for a simple, scalable solution, Gravity Water created a system that transforms rainwater into a reliable resource, helping communities build resilience against climate change and secure long-term water access. Gravity Water's success demonstrates how applying anthropology can drive meaningful change and help improve lives around the world.

YouTube Video

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Gravity Water (2019, March 29). Gravity Water Wins the 2018 NEXTies Non-Profit of the Year! [Video]. YouTube. https://www.youtube.com/watch?v=nBDxYEVZAbw&t=8s

To learn more about Gravity Water including potential intern and career opportunities, visit their website: https://www.gravitywater.org/about

Why Study Anthropology?

Ultimately, anthropology helps us think more critically about our own lives and more empathetically about others. It challenges assumptions, reveals hidden patterns, and shows us that the way we do things isn't the only way, or necessarily the best way. In an increasingly interconnected and complex world, the anthropological perspective is more relevant and valuable than ever.

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Nelson, Katie, Braff, Lara, and Aguilera, Kelsie. (2023). 1.2: The Subdisciplines *In Explorations: An Open Invitation to Biological Anthropology, first edition,* edited by Beth Shook, Katie Nelson, Kelsie Aguilera, and Lara Braff. Open Educational Resource, licensed under *CC BY-NC 4.0*.

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1.2: Key Anthropological Perspectives

The Holistic Approach

Anthropology is **holistic** in nature. Because humans are complex biological and social beings shaped by millions of years of evolution, we need to examine many different components to understand what it means to be human. Studying just one piece gives you a limited picture.

Think about it this way: if you were trying to explain **human variation** to someone with no background in the subject, where would you begin? Genetics? Skeletal anatomy? Diet and nutrition? Disease and immune response? How our bodies adapt to different environments – high altitude, extreme cold, or arid heat? Would you focus on a specific population – indigenous groups in the Amazon, pastoralists in East Africa, Arctic communities? Does the human body look and function the same across these contexts, and if not, why?



Figure $1.2.1a-c$: Human variation. a) Indigenous men from the Venezuelan Amazon. Fotofox, Public domain, via Wikimedia Commons; b) Maasai woman from Tanzania. Image by Dr. Ondřej Havelka (cestovatel), CC BY 4.0 via Wikimedia Commons; c) Inuit women and child from Greenland. Ansgar Walk, CC BY-SA 3.0, via Wikimedia Commons

How far back would you go? Would you examine recent evolutionary changes over the past few thousand years, adaptations from tens of thousands of years ago, or traits inherited from **hominin** ancestors millions of years in the past? Could any single individual or population perfectly represent the full range of human biological diversity, or would you need to draw on many different groups and time periods?

And what about the present? Human biology is constantly being shaped by the modern world. Urbanization, industrialized food systems, new infectious diseases, and digital technology such as social media, all interact with our bodies in ways than can accelerate, suppress, or alter biological processes entirely. A child's growth trajectory today may be influenced not just by genetics and local diet, but by exposure to antibiotics or ultra-processed foods, that reshape the gut microbiome in evolutionarily unprecedented ways. As children grow into adolescence, we're seeing how the hours spent on social media platforms are reshaping the brain, attention spans, and mental health in ways we are just beginning to understand.



Figure 1.2.2$a-c$: Young people absorbed in their screens. a) Young teen girls on devices. Photo by Kateryna Hliznitsova on Unsplash; b) Young teen boys using smartphones in school. Photo by Fajar Herlambang STUDIO on Unsplash; c) Adolescent girl staring into a smartphone screen. Photo by Johnny Cohen on Unsplash

The point is that all aspects of human biology are deeply interconnected and can't be fully understood in isolation. Our skeletons, immune systems, reproductive patterns, growth and development, and evolutionary history all influence one another in ways that only become visible when examined together. Any single biological trait can tell you both a great deal and almost nothing at the same time. Understanding the relationships between these components, and between biology, environment, and behavior, and increasingly, technology, is critical to grasping how and why humans vary across time and space.

A real world example of how a holistic perspective can help connect seemingly unconnected dots comes from studying improvement in infant mortality in Africa. Throughout the 2010s, infant death rates in rural African areas decreased dramatically, but researchers couldn't initially explain why. Parents weren't doing anything differently, governments weren't providing better services, and aid agencies hadn't increased resources. The one thing that had changed was the spread of mobile phones (Flückiger & Ludwig 2023; Mensah, Tafere & Abay 2022).



Figure 1.2.3: Mother and baby in Africa. Image by Wilhan José Gomes wjgomes from Pixabay

Using a holistic approach, they discovered the connections: mobile phones allowed parents to call healthcare workers for advice, coordinate transportation to clinics during emergencies, and receive text reminders about vaccinations. What seemed

like unrelated phenomena—technology and infant health—turned out to be deeply connected. You couldn't understand the improvement in infant mortality by looking at healthcare alone or technology alone. You needed to see how these different aspects of life intersected and influenced each other.

The same is true when studying any aspect of human biology and culture, or bio-cultural evolution. We need to examine multiple dimensions and understand how different elements connect to create the whole picture.

Intersectionality and Holism

We can see the holistic approach in action through the work of UCLA Professor Kimberlé Crenshaw, who developed the concept of **intersectionality**. Crenshaw observed that while some American media coverage brings attention to police violence against unarmed Black men, American society largely ignores or downplays similar violence against unarmed Black women. Why?

By examining this holistically, anthropologists and social scientists understand that the forms of marginalization Black women face are harder to address because their race *and* gender intersect to create a unique type of discrimination. Black women in America are marginalized differently than Black men are, and differently than white women are. We can't study these experiences separately—we must consider how beliefs about race *and* gender interact together in American culture. Crenshaw calls this **intersectionality**: all of our different identities (race, gender, class, nationality, ability, sexuality, age, immigration status, etc.) intersect with one another to create unique lived experiences.

Here are some additional examples that help to illustrate this important concept:

Healthcare disparities: Black women in the U.S. are nearly three times more likely to die from pregnancy-related complications than white women. This can't be explained by race alone or economic class alone—it's the intersection of race, gender, and how medical professionals' biases affect the treatment Black women receive.

Representation in media: When Marvel introduced Ms. Marvel (Kamala Khan), a Pakistani-American Muslim teenage superhero, it mattered to young people who'd never seen someone like themselves as a superhero. Their experience as fans intersected with their identity as Muslims, as South Asian Americans, as young women—all at once.

Workplace discrimination: A Latina woman applying for a tech job may face discrimination based on both her gender (in a male-dominated field) and her ethnicity. Her experience is different from a white woman's or a Latino man's in the same field—the intersection creates unique challenges.

Worldview

When we take a holistic approach, we're examining the "whole" of something. The whole of our culture shapes our **worldview,** or the lens through which we see and interpret everything around us.

Your worldview includes:

- Your understanding of "right" and "wrong"
- Your ideas about how people should behave
- Your understanding of gender roles and expectations
- Your sense of what's "fair" or "just"
- Your understanding of history and whose stories matter
- Your assumptions about family structure, success, time, personal space, and communication

Although it may seem obvious, it's important to point out that no two people have identical worldviews**,** not even two members of the same culture. This is because worldviews are **culturally specific**—they're heavily shaped by our cultural surroundings. By holistically examining all the elements that influence a person's life, we can better understand how different worldviews emerge.

Enculturation: How We Learn Our Worldview

The process through which we learn our culture and worldview is called **enculturation**. You've been enculturated your entire life through:

- **Family**: Teaching you what "proper" behavior looks like
- **Friends and peers**: Rewarding certain behaviors and discouraging others
- **Media**: TV shows, movies, TikTok, YouTube, Instagram—all showing you what's "normal," desirable, or aspirational
- **Education**: Teachers and schools communicating what knowledge matters and how to succeed
- **Medical and mental health professionals**: Defining what's "healthy" and "unhealthy"
- **Religious or spiritual leaders**: Shaping moral frameworks
- **Algorithms**: Social media feeds that show you content based on what you've engaged with before, potentially creating echo chambers



Figure 1.2.4: Pieces of the human puzzle that can shape our worldview. Canva design.

Let's examine some specific examples of enculturation in action through what seem like some straightforward concepts:

Beauty standards: Human bodies are incredibly diverse—weight, height, skin tone, hair texture, facial features all vary widely. Our ideas of what's "beautiful" or "attractive" are largely defined by powerful cultural forces that typically promote very narrow ideals. When you grow up seeing only certain body types on magazine covers, in movies, as Instagram influencers, and even in video game avatars, you're enculturated to value a tiny sampling of human diversity.

These standards also vary dramatically across cultures. In the 1990s, mainstream American culture idealized extreme thinness in women. But in many Pacific Island societies like Fiji and Tonga, as well as parts of the Caribbean and Africa, larger bodies have traditionally been preferred and associated with health, wealth, social connection, and beauty. In these cultures, a larger body size signified that you had a strong social network of people who cared for you and shared their resources with you. (Becker 1995). The "ideal" isn't universal—it's culturally constructed and varies across both time and place.

Success and power: Nobody's born knowing what "success" looks like. Is success measured by wealth? By having a large family? By community respect? By followers on social media? By job title? By creative achievement? By spiritual enlightenment? By work-life balance?

These concepts vary dramatically across generations and societies. We learn culturally-specific ideas of success throughout our lives as parents, teachers, influencers, celebrities, and media narratives define and reinforce them. Your grandparents' generation might define success as job stability and homeownership. Your generation might value entrepreneurship, flexibility, or making a positive social impact. Neither is inherently "correct," they're simply different cultural values shaped by different historical and economic contexts.

Communication styles: Are you supposed to make direct eye contact when talking to someone, or is that disrespectful? Should you get straight to the point or build relationship first? Is silence awkward or respectful? Is it rude to interrupt or is that how you show you're engaged? All of these norms are culturally learned, and what feels "natural" to you is actually enculturation at work.



Figure 1.2.5: Students working together on a project. Image by StockSnap from Pixabay

Cultural Relativism

Another central goal of anthropology is to promote **cultural relativism** and counter **ethnocentrism**. **Ethnocentrism** is the tendency to view your own culture as superior and to use your culture's standards to judge all others. **In contrast, cultural relativism** is the principle that all cultural beliefs and practices should be understood within their own context, not judged by the standards of another culture. To judge a culture based on the rules you learned in *your* cultural setting is always a biased, pointless exercise. Instead of judging from an outsider's perspective (as early anthropologists unfortunately did), we strive to understand cultures on their own terms—through their own culturally-specific logic.

For example, imagine you're working on a group project with international students. Your Vietnamese classmate doesn't make much small talk and gets straight to business, which you initially interpret as cold or unfriendly. Meanwhile, they might find American small talk exhausting and fake—why are people asking "how are you?" when they don't actually want a real answer?

An **ethnocentric** response would be: "All that small talk is fake and a waste of time. Why can't people just say what they mean instead of beating around the bush?"

A **culturally relativistic** response would be: "Different cultures have different communication norms. Direct communication shows respect for time in some cultures, while relationship-building through small talk shows respect for the person in others. Neither is inherently better."

Or, consider how in many cultures, adult children are expected to live with or near their parents and contribute to household expenses or elderly care. In mainstream U.S. culture, young adults are often encouraged to move out and become independent as a marker of success.

An **ethnocentric** response would be: "Moving out and being independent is the mature, healthy thing to do. Living with your parents as an adult means you're dependent and not really an adult yet."

A **culturally relativistic** response would be: "Different cultures organize family relationships differently based on economic systems, values around individualism versus collectivism, and different historical contexts. Both systems make sense within their own cultural logic."

The Limits of Cultural Relativism

An important thing to remember is that practicing cultural relativism doesn't mean you have to agree with or like all cultural practices. It means you should always strive to *understand* how they make sense to cultural insiders within their own context. Throughout this course and in life, you'll encounter cultural beliefs and practices quite different from your own. Some might

challenge your values. That's okay. The goal isn't to abandon your own values or remain neutral, it's to develop the intellectual skill of seeing things from multiple perspectives. In other words, the goal is cross-cultural understanding---even if we don't agree with or like a specific belief or practice. But it's also important to point out that anthropologists do recognize that some practices cause genuine harm. Cultural relativism as an analytical tool (understanding *why* something exists in its cultural context) is different from moral relativism (believing all practices are equally ethical). We can understand the cultural logic behind a practice while still advocating for human rights and working against harm.

Recognizing Our Biases

We all carry **implicit biases**: unconscious attitudes and assumptions shaped by our enculturation that influences our perceptions without us realizing it. These biases often lead us toward ethnocentrism because we believe our own culture is best or "natural." What feels "normal" or "natural" to you is actually just familiar. The key is:

- Recognizing our ethnocentric reactions when they happen
- Acknowledging that all cultures are constructed, not natural
- Adjusting our perspective to understand things in context
- Practicing curiosity instead of judgment

By trying to understand and appreciate cultural diversity, we promote better communication, potentially reduce conflict, and often learn surprising things that challenge our assumptions. Learning to see your own culture as one option among many, and to understand why other approaches make sense in their contexts, is transformative. Developing this anthropological intelligence will help you navigate diverse workplaces, communities, and relationships throughout your life.



Figure 1.2.6: Appreciating cultural diversity. Image by Gerd Altmann from Pixabay

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1.3: The Scope of Biological Anthropology

The Scope of Biological Anthropology

Just as anthropology as a whole takes a wide-ranging, holistic approach to studying humans, biological anthropology does the same from a biological perspective. The field is divided into at least six **subfields**: primatology, paleoanthropology, molecular anthropology, bio-archaeology, forensic anthropology, and human biology.



Figure 1.3.1: Biological anthropology includes primatology, paleoanthropology, bioarchaeology, molecular anthropology, forensic anthropology, and human biology. Credit: Subfields of biological anthropology (Figure 1.16) original to Explorations: An Open Invitation to Biological Anthropology by Mary Nelson is under a CC BY-NC 4.0 License

Each subfield tackles different questions about what it means to be human biologically. Researchers in these areas work to answer some pretty big questions about our species:

- What is our place in nature? How are we related to other organisms? What makes us unique?
- What are our origins? What influenced our evolution?
- How and when did we move across the globe?
- How are humans around the world different from and similar to each other? What drives these patterns? How do we continue to evolve?

A quick note on terminology here: We use ***subdiscipline*** to refer to the four major areas of anthropology (biological, cultural, archaeological, and linguistic), and ***subfield*** for the specializations within biological anthropology.

Molecular Anthropology

Molecular anthropologists use cutting-edge genetic techniques to compare ancient and modern populations, studying everything from humans to our primate relatives. By examining DNA sequences, they can figure out how closely related different populations are and identify major evolutionary events like population bottlenecks or rapid expansions.

This field has produced some remarkable breakthroughs in recent years. For example, Swedish scientist Svante Pääbo won the 2022 Nobel Prize in Physiology or Medicine for successfully sequencing DNA from 40,000-year-old Neanderthal bones. Working with such ancient DNA is incredibly challenging because it degrades over time and is easily contaminated. Pääbo and his team developed specialized clean rooms and advanced sequencing techniques to overcome these obstacles, revolutionizing how we study extinct human species.



Figure 1.3.2: Paleo-geneticist and 2022 Nobel Prize Winner Svante Pääbo. The Royal Society, CC BY-SA 3.0, via Wikimedia Commons

Their work revealed that most people of non-African descent carry 1-2% Neanderthal DNA—evidence that our ancestors interbred with Neanderthals thousands of years ago. Some of these inherited genes still affect us today, influencing everything from our immune responses to how we process modern day diseases.

Molecular anthropology also encompasses the study of epigenetics which are chemical modifications to DNA that can turn genes on or off without changing the DNA sequence itself. These modifications can be influenced by experiences and environmental conditions, and some can even be passed down to future generations. This rapidly evolving field continues to push the boundaries of what we can learn about our ancestors, adaptation, and evolution.

Primatology

Primatologists study the anatomy, behavior, ecology, and genetics of living and extinct nonhuman primates including apes, monkeys, tarsiers, lemurs, and lorises. Why study our primate cousins? Because they're our closest living biological relatives, and understanding them helps us understand ourselves and our evolutionary journey.



Figure 1.3.3: Sculpture of Jane Goodall and David Greybeard outside the Field Museum in Chicago. Image by Geary is in the public domain (CC0), via Wikimedia Commons

Legendary primatologist Jane Goodall began her groundbreaking chimpanzee research in Tanzania in 1960, revolutionizing our understanding of chimp behavior and culture. Her early work shattered scientific assumptions when she documented chimpanzees making and using tools (stripping leaves from twigs to "fish" for termites), showing that tool use wasn't uniquely human. She observed chimps engaging in complex social politics and displaying emotions like joy, sadness, and grief. With over six decades of research in the field, Goodall was able to document how young chimps learn from their mothers and transmit knowledge across generations.

With about 60% of primate species threatened with extinction due to climate change, habitat loss, and hunting, the work of primatologists plays an increasingly critical role in conservation efforts to save these species before it's too late.

Paleoanthropology

Paleoanthropologists are like detectives of the deep past, piecing together the story of our human ancestors relying on physical evidence such as fossilized bones, stone tools, and the environments where these items are discovered.



Figure 1.3.4:Donald Johanson and an Australopithecus fossil skull. Credit: Donald Johanson 2009 by Julesasu has been designated to the public domain (CC0).

Recent discoveries have transformed our understanding of human evolution from a simple linear progression to a complex family tree where multiple human species coexisted and interacted across vast distances. For instance, a 2026 study in *Nature* describes nearly 800,000-year-old fossils from a site in Morocco (de Lazaro 2026). The discovery suggests that North Africa was an important "crossroads" for early human ancestors migrating between continents. These fossils may help clarify the evolutionary relationships between *Homo sapiens, Neanderthals,* and *Denisovans* (Science Daily 2026).

Bioarchaeology

Bioarchaeologists study human skeletal remains alongside soils, artifacts, and materials found with them. They combine methods from skeletal biology, archaeology, and osteology to answer questions about how past populations lived and died, their health, nutritional status, diseases, injuries, and burial practices.

What makes bioarchaeology unique is its emphasis on *context*. Rather than studying bones in isolation, bioarchaeologists examine where and how remains were found, taking a biocultural approach that recognizes how biology, culture, and environment are interconnected. They typically study entire populations rather than just individuals, revealing broader patterns.

Forensic Anthropology

Forensic anthropologists apply similar techniques as bioarchaeologists, but to more recent cases. They develop biological

profiles for unidentified individuals by estimating sex, age at death, height, ancestry, and identifying unique features like old injuries or diseases. They also assist law enforcement at crime or disaster scenes, helping to search for and recover human remains.

If you've watched the TV show *Bones*, you've seen a (highly dramatized) version of this work. While the show features real forensic anthropology techniques, it takes major creative liberties. In reality, forensic anthropologists don't trace evidence like hair or fibers, don't run DNA tests in the lab, definitely don't carry weapons, and don't single-handedly solve crimes. They're part of a larger investigative team. Real forensic anthropologists have been crucial in identifying victims of mass disasters and human rights violations. This is yet another form of applied anthropology using academic knowledge to solve real-world problems and bring closure to families who have tragically lost loved ones.

Human Biology

Many biological anthropologists work in what's broadly called 'human biology,' exploring how the human body is shaped by different physical environments, cultural practices, and nutrition. This includes studying **human variation**—the physiological differences among people around the world.

Some researchers focus on human adaptations to extreme environments. For instance, Tibetan populations have evolved genetic adaptations that help them thrive at high altitudes where oxygen is scarce. These adaptations developed in just a few thousand years, making it one of the fastest evolutionary changes in humans on record. Other researchers might study how factors like stress, pollution, or climate change are affecting human health in real time.

RESEARCHER PROFILE: High Altitude Adaptions – The work of Emilia Huerta-Sánchez



Figure 1.3.5: Dr. Emilia Huerta-Sánchez. Photo by Dave Strauss.

It wasn't long ago that population geneticist Emilia Huerta-Sánchez took her first biology class. As a math major and then an applied math graduate student, she'd just never had a reason to study biology—that is, until her Ph.D. advisor suggested that she apply her statistical skills to a problem in evolution: what occurs in a population when the strength of natural selection varies from generation to generation? For Emilia, biology's lure lies in human evolution. "We know that as humans have colonized the world, they've encountered different environments—changes in temperature, changes in diet, changes in pathogen exposure, changes in altitude," she explains. "How did they do this? What genetic mutations provided them with the ability to live in those environments?" Emilia is particularly intrigued by Tibetan highlanders, who thrive at 13,000 feet above sea level—a height that, for most people, would lead to serious altitude sickness. How do the Tibetans do it? Emilia's current work aims to uncover the unique adaptations that make it possible to live in some of the highest regions on Earth.

Adapted from the UC Museum of Paleontology (UCMP) for the Understanding Evolution (UE) website licensed under an Attribution-NonCommercial-ShareAlike 4.0 (BY-NC-SA 4.0) Creative Commons License.

Pieces to the Puzzle of What It Means to Be Human

Despite their different focuses, all biological anthropologists share a commitment to answering anthropology's central question: What makes us human? The six subfields of biological anthropology each contribute to understanding what it means to be human in a biological context. From analyzing ancient DNA to studying our primate cousins, from examining skeletons to tracking how we adapt to different environments, biological anthropology uses scientific methods to piece together the story of how we became the complex, adaptable species we are today.

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1.4: Anthropology and Colonialism

Anthropology and Colonialism: Confronting Our Discipline's Past

Before we dive deeper into anthropology, we need to address the field's connection to colonialism. This legacy still very much shapes our world today, including the community where you live, the languages you speak, and the inequalities you see around you.

When Did Anthropology Actually Begin?

Pinpointing the "beginning" of anthropology is tricky because humans have always been curious about each other. Long before anthropology became an official academic field, philosophers and travelers from ancient societies across the world, in China, the Islamic world, Greece, and elsewhere, studied and wrote about cultural diversity (Guest 2020). For most of human history, studying other cultures had little practical value to those in power.

That changed dramatically during the Era of European expansion (roughly 16th-20th centuries), when European countries competed to control land, resources, and people across the globe. Colonial governments faced a problem: people don't like being controlled by foreign powers, and they resist. This is where early anthropologists saw an opportunity to rebrand their work as useful to colonial administrators, operating on a simple but troubling premise: if you understand a people, you can better control them (Kuper 2006).

What is Colonialism and Why Does It Matter Now?

Colonialism refers to the control of land and its people by a foreign power. While a few colonies still exist today, colonialism peaked between the 16th and 20th centuries when European powers sought to dominate the world and extract its resources—minerals, gems, waterways, spices, and in many cases, people. In colonial systems, Indigenous peoples were never treated as equals. Sometimes they were seen as obstacles to be removed. Other times they were viewed as resources to be exploited through slavery and forced labor. In all cases, they were denied basic human rights and dignity.

Pull up a world map and look at which regions were colonized. With arguably only two exceptions—Lesotho and Ethiopia—the entire African continent was colonized during European expansion. So were all of South America, the Pacific Islands, more than half of the Middle East, and large parts of Asia. Now, look at global wealth distribution today. Notice something? The richest nations tend to be European or of European heritage, while many of the world's poorest nations fall along former colonial borders. Sadly, but surely, this is not a coincidence.

When European colonial powers extracted valuable resources and enslaved people for free labor, they systematically enriched themselves while impoverishing colonized populations. This wealth disparity enabled technological advancement in Europe and European-heritage nations while repeatedly weakening robbed nations, creating inequalities that persist today in healthcare access, educational resources, infrastructure, and economic opportunity.

Colonialism and Your Own Community

You don't have to look across oceans to see colonialism's impact—it's right here in the United States. The Eastern U.S. was colonized by the British until American colonists rebelled. The Southern states were colonized by France before being sold to the U.S. The Southwest was colonized by Spain, briefly became part of Mexico after Mexican independence, then was taken by the U.S. through warfare with California coming under American control in 1850.

It's important to remember that we live in a former colony**.** Our colonial heritage shapes nearly every aspect of our lives:

- **Languages**: The two most common languages in the U.S. – English and Spanish – are colonizers' languages, not Indigenous languages.
- **Religion**: Christianity, the majority religion, was brought by colonizers.
- **Legal systems:** Our judicial structure, laws, and legal procedures derive from European systems,

- **Cultural norms**: Our dominant ideas about gender roles, holidays, dress, even what counts as "professional" or "academic" behavior – these largely reflect European colonial heritage.

Understanding this context is essential as we examine contemporary issues throughout this course. The modern world was shaped by colonialism, and we're still living with its consequences.

What Did Colonial Anthropologists Actually Do?

Anthropologists working for or alongside colonial regimes produced work that supported colonial control in several ways:

Producing racist propaganda: Early anthropologists constructed Indigenous peoples as "savage" or "less than human" while portraying Europeans as "civilized." Because these anthropologists were viewed as experts, Europeans back home believed them. This racist scholarship justified the brutal control European powers exercised over colonized populations (Crewe & Axelby 2014; Kuper 2006)

Creating cultural hierarchies: European anthropologists assumed their culture was inherently superior and ranked all other cultures against this standard. This logic was fundamentally flawed—the European standard wasn't universal or objective, but it was used to justify domination and exploitation (ibid; Trouillot 2003; Mines 2003).

Collecting census data: By surveying populations—counting people, categorizing them—colonial governments gathered intelligence they could use for control (ibid).

Learning local languages and customs: Understanding how people communicated made it easier to manipulate, divide, or suppress them (ibid).

Studying judicial systems: Colonial powers learned about local justice systems not to respect them, but to co-opt or replace them for better control (ibid).

The "Armchair Anthropologist" Problem

Cultural anthropology during the colonial era looked nothing like today's anthropology. We call these early scholars **armchair anthropologists** because many spent little to no time with the people they claimed to study (Guest 2020) Some never even visited the communities they wrote about! Instead, they relied on secondhand information from missionaries and colonial officials, then published lengthy books claiming expertise.

As you can imagine, this "research" was deeply unreliable and often bore little resemblance to actual Indigenous cultures. It did, however, serve colonial interests by providing an academic veneer to racist policies.

The exact relationship between early anthropology and colonialism is still debated among scholars today, however, we do know that:

- Anthropologists received funding and access to Indigenous lands through colonial connections (Guest 2020; Crewe & Axelby 2014; Kuper 2006).
- Many marketed themselves as useful to colonial governments to secure funding and research access (Kuper 2006).
- Some anthropologist-administrators directly advised colonial policy (ibid).

But scholars disagree on the details. Anthropologist Adam Kuper (2006) argues that field anthropologists were often ignored by officials as eccentrics. Talal Asad contends that anthropological contributions were too academic to help colonial administrators much (1973, 1991).

What is certain, though, is that early anthropology developed within a worldview of white European supremacy (Wolf 1982; Zuberi & Bonilla-Silva 2008). Whether individual anthropologists actively helped or resisted colonial efforts, they were working within a framework that divided the world into "civilized" Europeans versus everyone else. This binary worldview was fundamentally flawed and caused enormous harm (Troulliot 2003; Wolf 1982).

Modern anthropologists have a responsibility to acknowledge this history, address its ongoing impacts, and work actively to decolonize our field.

The Importance of Critical Thinking

This brings us to a crucial point about this class, and really, about all your classes: always think critically about what you read and who's saying it.

Scientists and academics are human. We all have political viewpoints, personal biases, and academic agendas shaped by our experiences and worldviews. This inevitably comes through in our work. Some colonial anthropologists deliberately constructed Indigenous peoples as subhuman to justify oppression. Some contemporary anthropologists, despite good intentions, might overlook harmful practices within communities they study or fail to recognize their own blind spots.

As a student, your job isn't to passively absorb information, it's to stay curious and question everything. Always ask yourself:

- Who conducted this research and what was their perspective?
- Who benefited from this knowledge being produced?
- Whose voices are centered, and whose are missing?
- What assumptions underlie these conclusions?
- How might my own background shape how I interpret this material?

Critical thinking is not about rejecting all scholarship or becoming cynical. It's about engaging thoughtfully with ideas, recognizing that knowledge is always produced by people with particular positions and interests, and developing your own informed perspectives.

This skill—thinking critically about power, perspective, and knowledge production—is one of the most valuable things you'll take away from this course. It applies far beyond anthropology, helping you navigate media, politics, workplace dynamics, and life itself.

As we move forward in this course, remember that anthropology's problematic past doesn't make the discipline worthless—it makes our commitment to doing better absolutely essential. Modern anthropology, at its best, centers the voices of marginalized communities, challenges inequality, and uses cross-cultural understanding to promote justice rather than control. Achieving that goal requires honestly confronting where we came from.

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1.5: Key Terms

Armchair anthropology – refers to 19th and early 20th century scholars who developed theories about human culture and evolution from their home libraries, often relying on second hand reports from explorers and missionaries, rather than through own direct observations through fieldwork.

Artifacts – objects made by humans such as pottery, tools, clothing, or art

Code switching – refers to alternating between languages or mannerisms to fit into different contexts.

Colonialism – process through which a foreign power gains control over and occupies another country, relying on political domination, economic exploitation, resource extraction, and marginalization, oppression, or elimination of original populations.

Comparative – a research method used to analyze similarities and differences across different cultures, historical time periods and between humans and other primates.

Cultural relativism - the principle of understanding an individual's beliefs, values, and practices within the context of their own culture, rather than judging them by the standards of another

Cultural resource management - a professional field of anthropology dedicated to identifying, assesing, and preserving cultural resources including archaeological sites, historic buildings, and landscapes, usually in compliance with environmental regulations.

Culturally specific - refers to the beliefs, behaviors, symbols, or language that hold unique, often untranslatable significance within a particular cultural group or context

Enculturation - the process by which individuals learn and absorb the norms, values, behaviors, and language of their own culture

Ethnocentrism - to judge other cultures against the standards and values of one's own culture while also viewing one's own culture as superior to others

Ethnography – a qualitative research method that includes long-term participant observation fieldwork to get an in-depth understanding of people, culture, and behavior.

Holistic – the idea that the parts of a system interconnect and interact to make up the whole.

Hominin – humans and their extinct bipedal relatives

Human variation – the range of forms of any human characteristic, such as body shape or skin color; the diversity in human characteristics

Intersectionality – an analytical framework for understanding how social identities such as race, gender, class, sexuality, and ability overlap to create unique experiences and combinations of privilege or oppression

Participant observation – a research method used in cultural anthropology that involves living with, observing, and participating in the same activities as the people one studies.

Relativist – or, cultural relativism, is a perspective that attempts to understand specific cultural practice, beliefs, and values within their own context

Subdisciplines – the four major areas that make up the discipline of anthropology: Biological anthropology, Cultural anthropology, Archaeology, and Linguistic anthropology. Applied anthropology is sometimes considered to be a fifth subdiscipline.

Subfields – In this text, *subfield* refers to the different specializations within biological anthropology, including primatology, paleoanthropology, molecular anthropology, bioarchaeology, forensic anthropology, and human biology.

Worldview - the lens through which we view and interpret the world and everything around us

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2: AN EVOLUTIONARY WORLDVIEW

Learning Objectives

- Evaluate different ways of knowing that shape understandings of our human story.
- Describe how science is an on-going process that requires rethinking new evidence and revising explanations.
- Identify common misconceptions related to evolution.
- Consider the value of critical thinking and mental flexibility in a rapidly changing world.

2.1: Ways of Knowing

2.2: Science as Process

2.3: Evolution, Religion, and Society

2.4: Misconceptions About Evolution

2.5: Critical Thinking

2.6: Key Terms

2.7: References

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2.1: Ways of Knowing

Introduction to Knowledge Systems

In anthropology, we recognize that there are many ways people come to know things. Think about your own life: you might know that coffee helps you stay awake during early morning classes because you've experienced the effects of caffeine firsthand. You might know that texting while driving is dangerous not from personal experience (hopefully!), but from driver's education classes, news stories, and warnings from family members. The degree to which humans rely on and benefit from the experiential knowledge of others is a fundamental characteristic of what makes us human.

A unified way of knowing that is shared by a group of people and is used to explain and predict phenomena is called a **knowledge system**. Human knowledge systems are remarkably diverse, reflecting the wide range of cultures and societies throughout the world and across time. Different individuals, cultures, and societies may place more value on one type of knowing than another, though most people draw on multiple knowledge systems throughout their lives. Science and religion are two common knowledge systems that humans use to understand our world.

Understanding vs. Belief: How Science and Religion Differ

Science and religion are both knowledge systems, but they operate quite differently. The type of knowledge gained from science is called scientific **understanding**. Scientific understanding can change and relies on evidence and rigorous, repeated testing. Religious ways of knowing are called **belief**, which differs from scientific understanding because it does not require repeated testing or validation. Instead, religious belief relies on trust and **faith**.

As a college student navigating the world, you already know that not all elements of human life can be proven or disproven through scientific research. Religion is a prime example. By its very nature, religion is defined by the faith that people have in its truth. Faith requires the absence of empirical proof to be faith. If you could prove a religious claim using the scientific method—measuring it, testing it, replicating the results—it would cease to be a matter of faith and would become a scientific hypothesis. Religion is thus its own method of making sense of the world through observation and experience.

However, just because religious claims cannot be examined through the scientific method doesn't mean that religion isn't real. Religions shape people's behaviors, help communities survive through collective responsibility and care-taking, and can transform the way that adherents literally perceive the world. Think about how religious observances affect daily life: Muslims pray five times a day facing Mecca; Orthodox Jews refrain from work on the Sabbath; many Christians observe Lent by giving up something meaningful. These are very real, tangible, and often measurable effects that religion has on life.

Human Origins: Multiple Perspectives

Different religious traditions offer different perspectives on human origins. Nearly every culture and society has a unique origin story that explains where they came from and how they came to be who they are today. The Navajo (Diné) tell of emergence through different worlds; the ancient Greeks spoke of Prometheus shaping humans from clay; the Judeo-Christian tradition describes creation in Genesis. These origin stories are often integrated into a culture's religious belief system. Many anthropologists study faith-based origin stories and other beliefs because they reveal how particular groups of people explain the world and their place in it. At the same time, anthropologists value scientific understanding as the basis for explaining how humans vary biologically and change over time. In other words, anthropologists value multiple knowledge systems and use them to understand the human condition in a broad and inclusive way.

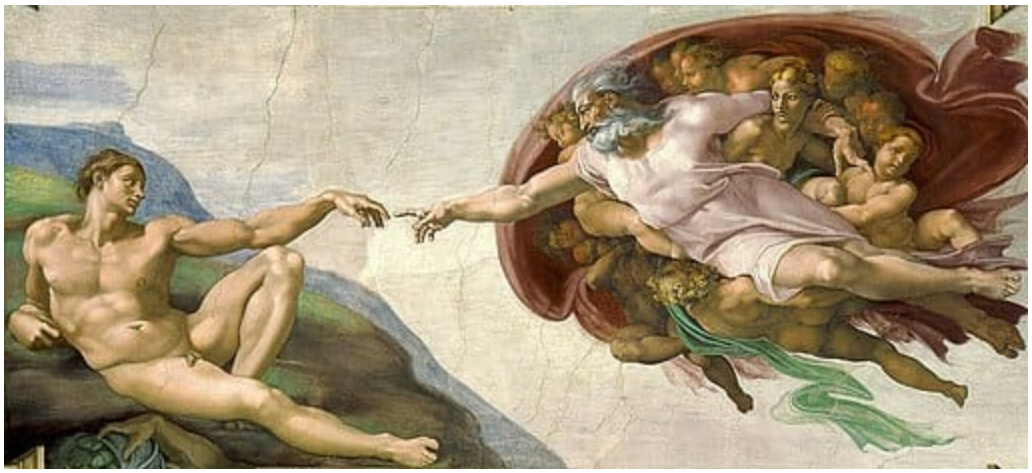


Figure 2.1.1:The Creation of Adam by Michelangelo, Sistine Chapel ceiling, Public domain, via Wikimedia Commons

Indigenous Knowledge Systems

Scientists often depend on local knowledge to understand elements of the natural world and to work collaboratively toward common goals (Estrada, et. Al. 2022). Many groups, including **indigenous** peoples, possess deep knowledge about the world developed through prolonged relationships with their environment. Indigenous knowledge systems—ways of knowing about and explaining the world that are specific to an indigenous community or group—are informed by empirical observation of specific environments and passed down over generations.

For example, indigenous peoples in the Pacific Northwest have detailed knowledge about salmon migration patterns, forest ecology, and sustainable harvesting practices developed over thousands of years. Similarly, Aboriginal Australians possess sophisticated understanding of fire ecology, using controlled burns to manage landscapes, knowledge that contemporary fire scientists are now recognizing as crucial for wildfire prevention. Indigenous knowledge of plant medicines has also led to the development of important pharmaceuticals: aspirin derives from willow bark, a pain reliever used by various indigenous groups for centuries.



Figure 2.1.2: Klamath Basin Tribes and allies from the commercial fishing and conservation organizations stage a rally calling for the removal of four Klamath River dams to help restore Klamath Salmon runs. Image by Patrick McCully, CC BY 2.0, via Wikimedia Commons



Figure 2.1.3: Pajé Vicente Xakriabá (Shaman) teaching about the medicinal plants of the cerrado in the territory of the Xakriabá people. Xakriabá Indigenous Territory (MG) Brazil. Image by Xakriaba, CC BY-SA 4.0, via Wikimedia Commons

While religion and indigenous knowledge systems may play complementary roles in helping anthropologists understand the human condition, they are distinct from science. The anthropological sub-discipline of biological anthropology is based on scientific ways of knowing about humans and human origins. In this class, we will emphasize what science tells us about how humans came to be and why we are the way we are today. However, we'll also acknowledge the limits of scientific understanding and the value of other ways of knowing in illuminating our human story.

Therefore, you do not need to believe in evolution to master this material, because belief is not a scientific way of knowing. For this class, you only need to understand the scientific perspective on evolution—the evidence, the mechanisms, and the reasoning that scientists use.

Throughout our lives, each of us works to reconcile and integrate into our worldview the different ways we have of knowing things. This is part of our lifelong intellectual journey and is one of the most exciting parts of learning. This class offers you an opportunity to expand your knowledge about humanity and yourself!

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Braff, Lara, Katie Nelson and Kelsie Aguilera (2023). 1.6 Ways of Knowing - Science, Faith, and Anthropology. In Beth Shook, Katie Nelson, Kelsie Aguilera and Lara Braff, Eds. *EXPLORATIONS: An Open Invitation to Biological Anthropology, Second Edition.* Open Educational Resource, licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

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2.2: Science as Process

Building Trust in Science

In a recent *Natural History Magazine* article, Sean Decatur (2025) lays out some of the problems that science is facing today. He notes that we are living in an era marked by science misinformation and disinformation, and we are witnessing a significant increase in public skepticism of science's value to the public good. Ironically, this is happening at a time when scientific discovery is experiencing a golden age. In biological anthropology alone, recent decades have brought remarkable breakthroughs: ancient DNA analysis has revealed that modern humans interbred with Neanderthals and Denisovans; new fossil discoveries like *Homo naledi* in South Africa have reshaped our understanding of human evolution; and advanced dating techniques have pushed back the timeline for early stone tool use to 3.3 million years ago. We can now sequence the genomes of our extinct relatives, trace human migration patterns across continents with unprecedented precision, and even extract proteins from fossils millions of years old.

As Decatur observes, the American scientific enterprise is becoming increasingly politicized and disrupted, in part because of fundamental misunderstandings of how it operates. When people don't understand that science is a process of continuous questioning and refinement, they may interpret changing scientific conclusions as evidence of failure or dishonesty rather than as signs of science working as it should. This misunderstanding has real consequences, affecting everything from public health responses to climate policy to research funding decisions.



Figure 2.2.1: March for Science Signs in Pittsburgh. Image by Mark Dixon from Pittsburgh, PA, CC BY 2.0, via Wikimedia Commons

Yet despite these advances, confusion about what science actually is may be undermining public trust. As Decatur points out, when people say "science," they might be referring to three different things: (1) science as a collection of people and institutions, (2) science as the process of generating new knowledge, or (3) science as the outcomes and products of discovery. "This lack of clarity may actually undermine public trust and confidence," according to Decatur (2025).

Part of the challenge is that scientific "facts" can and do change as new discoveries are made. For instance, scientists once believed humans had around 100,000 genes; the Human Genome Project revealed we actually have only about 20,000—fewer than many simpler organisms. For decades, scientists were certain that humans had no genetic relationship to Neanderthals but ancient DNA analysis proved them wrong, revealing that many people with European ancestry today carry 1-2% Neanderthal DNA. Our solar system went from having nine planets to eight when Pluto was reclassified as a dwarf planet in 2006.

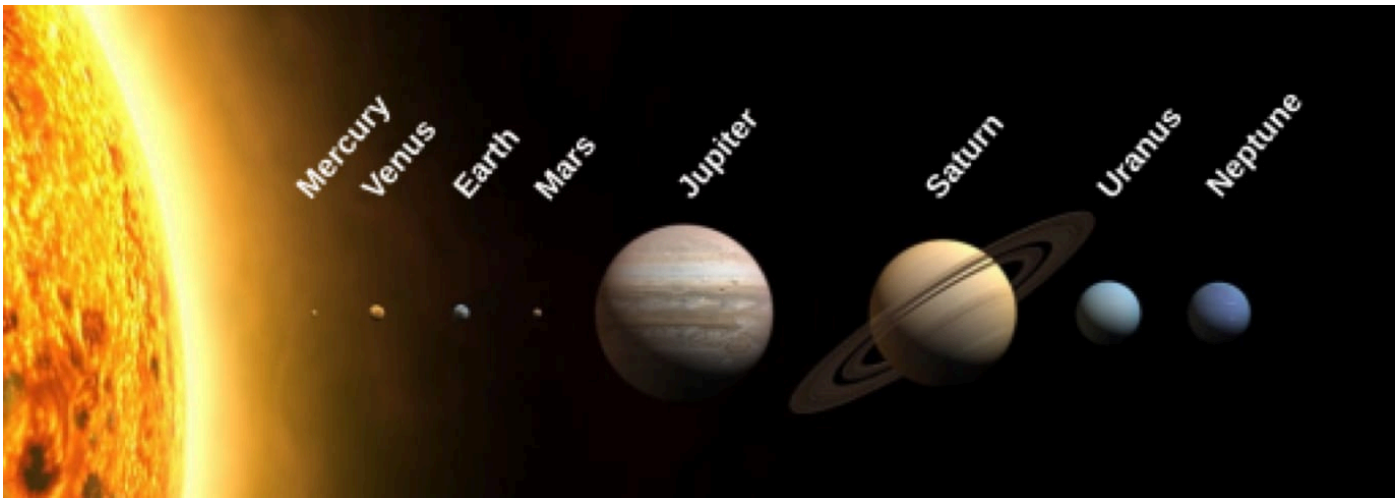


Figure 2.2.2:Our Solar System. Image by WP, CC BY-SA 3.0, via Wikimedia Commons

These changes might seem to undermine trust in science, but Decatur argues they actually demonstrate science working as it should. “Ultimately what we want people to trust are not individual facts, but rather the rigorous process of considering evidence that leads to conclusions,” he writes. As he notes, the problem with the catchphrase “believe science” is that it suggests we should not be skeptical about what is presented to us as scientific fact. Yet healthy skepticism is a feature of good scientific thinking. In science, we are continuously questioning: “Is that right?” “What if we looked at it this way instead?”

Decatur argues that “the best way to build confidence in science is to emphasize that science is a process, a method to explain phenomena, answer questions, and make predictions. It involves careful consideration and analysis of evidence. The process begins with and is fueled by questions.” Most of these questions stem from our desire to understand the world around us. For example: Why do chimpanzees use different tools in different regions—is this evidence of cultural transmission? How did early humans learn to make the first stone tools 3.3 million years ago? What happened to the Neanderthals?

Questions like these prompt hypotheses, which are then tested with evidence, resulting in acceptance, rejection, or support of the hypothesis. This process is ongoing: each new piece or batch of evidence can raise a new set of questions, prompting new evaluation and new opportunities for discovery. When ancient DNA analysis first revealed that humans and Neanderthals interbred, it raised new questions: When did this happen? Where? How often? What Neanderthal genes do we still carry? Do they affect our health today? Each answer leads to more questions, driving science forward. Challenging established ideas is how science continuously improves and expands our knowledge.



Figure 2.2.13:Neanderthal man and child from the Natural History museum exhibit in Vienna. Image by Jakub Hałun, CC BY-SA 4.0, via Wikimedia Commons

Science as a Social and Collaborative Process

Science itself is a social enterprise influenced by cultural values and funding priorities. Corporations are the biggest funders of scientific research, followed by government agencies like the National Science Foundation and the National Institutes of Health (which often fund research done by academics at colleges and universities). These organizations have tremendous influence on what research gets prioritized.

Consider this example: there are many diseases that the World Health Organization (WHO) has classified as "neglected tropical diseases," including dengue, leprosy, rabies, and hookworm. These diseases affect an estimated 1 billion people, mostly in impoverished areas. They can be as deadly as diseases that receive more attention, like HIV/AIDS and tuberculosis, yet receive comparatively little funding for research, drug development, and healthcare infrastructure. Why? Because the people affected often can't afford expensive treatments, making them less profitable for pharmaceutical companies to research.

The scientific process also depends heavily on collaboration and accountability within the scientific community. **Scholarly peer review** is a key mechanism: before research can be published in a journal or book, it must pass scrutiny from other experts in the field. Reviewers evaluate whether the methods were sound, the conclusions justified, and the research conducted ethically. Think of it as having your essay reviewed by your professor's colleagues before you can turn it in, except the reviewers are experts from around the world, and they're anonymous. This system helps keep scientists accountable and pushes the field toward better explanations.



Figure 2.2.4: Science Matters. Canva Design by Rachel Mitchell

How Science Works

Science is a particular way of knowing about the natural world. In science, explanations must be based on observations and evidence that others can verify. Scientists make observations, develop hypotheses to explain those observations, and test their hypotheses through experiments and additional observations.

Importantly, scientific knowledge is provisional—it's always open to revision based on new evidence. No scientific explanation is complete and final. Some explanations that scientists advance turn out to be incorrect when tested by further observations or experiments. New instruments may reveal the inadequacy of existing explanations. For instance, before the invention of the microscope, scientists didn't know about cells, bacteria, or viruses. The microscope revealed an entirely new dimension of biological understanding.

However, many scientific explanations have been so thoroughly tested that they are very unlikely to change in substantial ways. These explanations are accepted as accurate descriptions of the natural world. The atomic structure of matter, the genetic basis of heredity, the circulation of blood, gravitation and planetary motion, and the process of biological evolution by natural selection are examples of scientific explanations that have been overwhelmingly substantiated through countless observations

and experiments.



Figure 2.2.5: Strands of DNA. Image by geralt, CC0, via Wikimedia Commons

As we've covered previously, science is not the only way of knowing and understanding, but science is a way of knowing that differs from others in its dependence on **empirical** evidence and testable explanations. Because biological evolution accounts for events that are also central concerns of religion, including the origins of biological diversity and especially the origins of humans, evolution has been a contentious idea within society since it was first articulated by Charles Darwin and Alfred Russel Wallace in 1858.

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2.3: Evolution, Religion, and Society

Evolution and Modern Science

Scientific and technological advances have profoundly transformed human life. In the 19th century, most families could expect to lose one or more children to disease. Today, in the United States and other developed countries, childhood death from disease is uncommon. Consider how different your daily life would be without science-based technologies: the smartphone you use to stay connected, the medications you take when you're sick, the car or public transit that gets you to campus, even the food you eat—all were developed through the application of scientific knowledge.

The foundation of modern biological sciences is the theory of evolution. Understanding evolution is essential not just for biology, but for medicine, agriculture, environmental science, and even computer science (evolutionary algorithms help solve complex problems). When doctors need to understand why antibiotic-resistant bacteria are becoming more common, they're dealing with evolution in action. When agricultural scientists develop drought-resistant crops, they're applying principles of evolution.

Religion and Evolution: Compatibility

Today, many religious denominations accept that biological evolution has produced the diversity of living things over billions of years of Earth's history. The Catholic Church, many mainstream Protestant denominations, Reform and Conservative Judaism, and numerous other religious groups have issued statements observing that evolution and the tenets of their faiths are compatible. Scientists and theologians have written eloquently about their sense of awe and wonder at the history of the universe and of life on this planet, explaining that they see no conflict between their faith and the evidence for evolution.

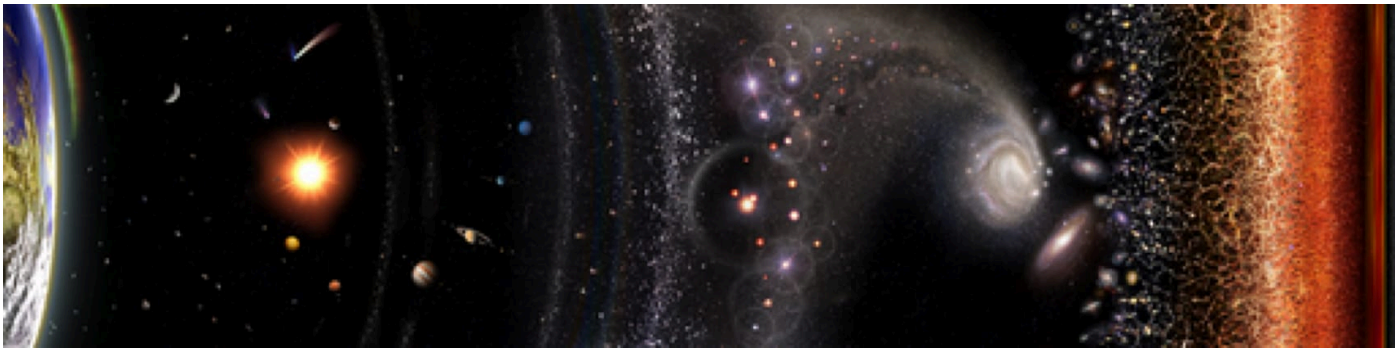


Figure 2.3.1: Observable universe. Image by Pablo Carlos Budassi, CC BY-SA 4.0 via Wikimedia Commons

For example, Francis Collins, a geneticist who led the Human Genome Project and served as director of the National Institutes of Health, has written extensively about his Christian faith and his acceptance of evolution. He argues that understanding the mechanisms of evolution deepens rather than diminishes his appreciation for creation (2007).

Religious denominations that do not accept evolution tend to be those that believe in strictly literal interpretations of religious texts. However, it's worth noting that even within Christianity, there's tremendous diversity of thought on this issue.

Science and religion are based on different aspects of human experience. In science, explanations must be based on evidence drawn from examining the natural world. Scientifically based observations or experiments that conflict with an explanation eventually must lead to modification or even abandonment of that explanation. Religious faith, in contrast, does not depend solely on empirical evidence, is not necessarily modified in the face of conflicting evidence, and typically involves supernatural forces or entities. Because they are not part of nature, supernatural entities cannot be investigated by science. In this sense, science and religion address different aspects of human understanding. Attempts to pit science and religion against each other create controversy where none need exist.



Figure 2.3.2: People praying in Bali. Photo by Wisnu Widjojo on Unsplash

Is Evolution a Theory or a Fact?

It is both. But that answer requires understanding what scientists mean by the words "theory" and "fact." In everyday usage, "**theory**" often refers to a hunch or speculation. When someone says, "I have a theory about why the Wi-Fi keeps dropping," they're usually drawing a conclusion based on limited or inconclusive evidence.

The formal scientific definition of "theory" is quite different. In science, a theory is a comprehensive explanation of some aspect of nature that is supported by a vast body of evidence. A scientific theory is not a guess—it's the highest form of scientific knowledge.

Many scientific theories are so well established that no new evidence is likely to alter them substantially. For example, no new evidence will demonstrate that the Earth does not orbit the Sun (heliocentric theory), that living things are not made of cells (cell theory), that matter is not composed of atoms (atomic theory), or that the Earth's surface is not divided into solid plates that have moved over geological timescales (plate tectonics theory). Like these other foundational scientific theories, the theory of evolution is supported by so many observations and confirming experiments that scientists are confident the basic components of the theory will not be overturned by new evidence.

However, like all scientific theories, evolution is subject to continuing refinement as new areas of science emerge. For instance, the field of **epigenetics**, the study of how environmental factors can affect gene expression without changing the DNA sequence, has added new dimensions to our understanding of how evolution works. New technologies like CRISPR gene editing and ancient DNA analysis enable observations and experiments that weren't possible even a decade ago, continually deepening our understanding.

One of the most useful properties of scientific theories is their ability to make predictions about natural events or phenomena that have not yet been observed. The theory of evolution, for example, predicted that we would find transitional fossils showing intermediate forms between major groups of organisms—and we have, repeatedly. It predicted that organisms sharing a recent common ancestor would have more similar DNA than distantly related organisms—and they do, consistently.

In science, a "**fact**" typically refers to an observation, measurement, or other form of evidence that can be expected to occur the same way under similar circumstances. However, scientists also use "fact" to refer to a scientific explanation that has been tested and confirmed so many times that there's no longer a compelling reason to keep testing it. In that respect, the past and continuing occurrence of evolution is a scientific fact. Because the evidence supporting it is so strong, scientists no longer question whether biological evolution has occurred and continues to occur. Instead, they investigate the mechanisms of evolution, how rapidly evolution can take place, and related questions.

Why Science Matters

Science and science-based technologies have transformed modern life, leading to major improvements in living standards, public health, and security. They've changed how we view the universe and how we think about ourselves in relation to the world around us.

Biological evolution is one of the most important ideas of modern science. Evolution is supported by abundant evidence from many different fields—paleontology, genetics, anatomy, embryology, biogeography, and molecular biology, among others. It underlies the modern biological sciences, including the biomedical sciences, and has applications in fields you might not expect, from computer science to psychology.

As individuals and as a society, you're now making decisions that will have profound consequences for future generations. Should we prioritize preserving biodiversity even when it conflicts with economic development? Should we reduce our use of fossil fuels to address climate change? To what extent should we use our understanding of genetics to alter the characteristics of living things, bring back extinct species, or select traits in our children? These aren't just abstract questions—they're decisions your generation will need to make.

None of these decisions can be made wisely without understanding biological evolution. As future voters, consumers, healthcare recipients, and perhaps parents, you need to understand evolution, its role within the broader scientific enterprise, and its vital implications for some of the most pressing social, cultural, and political issues of our time.



Figure 2.3.3: Young people at a climate change rally advocating for change. Photo by Li-An Lim on Unsplash

Because science and technology are so pervasive in modern society, you need a sound education in core scientific concepts, applications, and implications. To make informed decisions about public policies, from vaccine mandates to environmental regulations to funding for research, you need to know how scientific evidence supports those policies and whether that evidence was gathered using well-established scientific practices. Because evolution serves as a critical foundation of the biomedical and life sciences, helping students learn about and understand the scientific evidence, mechanisms, and implications of evolution is fundamental to a high-quality science education, and to being an informed citizen in the 21st century.

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2.4: Misconceptions About Evolution

Setting the Record Straight

Unfortunately, many people have persistent misconceptions about evolution. Some are simple misunderstandings — ideas that develop in the course of learning about evolution, possibly from school experiences and/or the media. Other misconceptions may stem from purposeful attempts to misrepresent evolution and undermine the public's understanding of this topic.

Here are some common misconceptions regarding evolution, as well as clarifications of these misconceptions.

MISCONCEPTION: Evolution is 'just' a theory.

CORRECTION: This misconception stems from a mix-up between casual and scientific use of the word *theory*. In everyday language, *theory* is often used to mean a hunch with little evidential support. Scientific theories, on the other hand, are broad explanations for a wide range of phenomena. In order to be accepted by the scientific community, a theory must be strongly supported by many different lines of evidence. Evolution is a well-supported and broadly accepted scientific theory; it is not 'just' a hunch. To learn more about the nature of scientific theories, visit the Understanding Science website.

MISCONCEPTION: Evolution is a theory about the origin of life.

CORRECTION: Evolutionary theory *does* encompass ideas and evidence regarding life's origins (e.g., whether or not it happened near a deep-sea vent, which organic molecules came first, etc.), but this is not the central focus of evolutionary **theory**. Most of evolutionary biology deals with how life changed *after* its origin. Regardless of how life started, afterwards it branched and diversified, and most studies of evolution are focused on those processes.

MISCONCEPTION: Evolutionary theory implies that life evolved (and continues to evolve) randomly, or by chance.

CORRECTION: Chance and **randomness** *do* factor into evolution and the history of life in many different ways; however, some important mechanisms of evolution are non-random and these make the overall process non-random. For example, consider the process of **natural selection**, which results in **adaptations** — features of organisms that appear to suit the environment in which the organisms live (e.g., the fit between a flower and its pollinator, the coordinated response of the immune system to pathogens, and the ability of bats to echolocate). Such amazing adaptations clearly did not come about "by chance." They evolved via a combination of random and non-random processes. The process of **mutation**, which generates **genetic variation**, is random, but selection is non-random. Selection favored variants that were better able to survive and reproduce (e.g., to be pollinated, to fend off pathogens, or to navigate in the dark). Over many generations of random mutation and non-random selection, complex adaptations evolved. To say that evolution happens "by chance" ignores half of the picture.

MISCONCEPTION: Evolution results in progress; organisms are always getting better through evolution.

CORRECTION: One important mechanism of evolution, natural selection, *does* result in the evolution of improved abilities to survive and reproduce; however, this does not mean that evolution is progressive — for several reasons. First, as described in a misconception below (link to "Natural selection produces organisms perfectly suited to their environments"), natural selection does not produce organisms perfectly suited to their environments. It often allows the survival of individuals with a range of traits — individuals that are "good enough" to survive. Hence, evolutionary change is not always necessary for species to persist. Many **taxa** (like some mosses, fungi, sharks, opossums, and crayfish) have changed little physically over great expanses of time. Second, there are other mechanisms of evolution that don't cause adaptive change. Mutation, **migration**, and **genetic drift** may cause **populations** to evolve in ways that are actually harmful overall or make them less suitable for their environments. For example, the Afrikaner population of South Africa has an unusually high frequency of the gene responsible for Huntington's disease because the gene version drifted to high frequency as the population grew from a small starting population. Finally, the whole idea of "progress" doesn't make sense when it comes to evolution. Climates change, rivers shift course, new competitors invade — and

an organism with traits that are beneficial in one situation may be poorly equipped for survival when the environment changes. And even if we focus on a single environment and habitat, the idea of how to measure "progress" is skewed by the perspective of the observer. From a plant's perspective, the best measure of progress might be photosynthetic ability; from a spider's it might be the efficiency of a venom delivery system; from a human's, cognitive ability. It is tempting to see evolution as a grand progressive ladder with *Homo sapiens* emerging at the top. But evolution produces a tree, not a ladder — and we are just one of many twigs on the tree.

MISCONCEPTION: Individual organisms can evolve during a single lifespan.

CORRECTION: Evolutionary change is based on changes in the genetic makeup of populations over time. Populations, not individual organisms, evolve. Changes in an individual over the course of its lifetime may be **developmental** (e.g., a male bird growing more colorful plumage as it reaches sexual maturity) or may be caused by how the environment affects an organism (e.g., a bird losing feathers because it is infected with many parasites); however, these shifts are not caused by changes in its **genes**. While it would be handy if there were a way for environmental changes to cause adaptive changes in our genes — who wouldn't want a gene for malaria resistance to come along with a vacation to Mozambique? — evolution just doesn't work that way. New gene variants (i.e., **alleles**) are produced by random mutation, and over the course of many generations, natural selection may favor advantageous variants, causing them to become more common in the population.

MISCONCEPTION: Evolution only occurs slowly and gradually.

CORRECTION: Evolution occurs slowly and gradually, but it can also occur rapidly. We have many examples of slow and steady evolution — for example, the gradual evolution of whales from their land-dwelling, mammalian ancestors, as documented in the fossil record. But we also know of many cases in which evolution has occurred rapidly and we can observe rapid evolution going on around us all the time. Over the past 50 years, we've observed squirrels evolve new breeding times in response to climate change, a fish species evolve resistance to toxins dumped into the Hudson River, and a host of microbes evolve resistance to new drugs we've developed. Many different factors can foster rapid evolution — small population size, short generation time, big shifts in environmental conditions — and the evidence makes it clear that this has happened many times.

MISCONCEPTION: Evolution and religion are incompatible.

CORRECTION: Because of some individuals and groups stridently declaring their beliefs, it's easy to get the impression that science (which includes evolution) and religion are at war; however, the idea that one always has to choose between science and religion is incorrect. People of many different faiths and levels of scientific expertise see no contradiction at all between science and religion. For many of these people, science and religion simply deal with different realms. Science deals with natural causes for natural phenomena, while religion deals with beliefs that are beyond the natural world. Of course, some religious beliefs explicitly contradict science (e.g., the belief that the world and all life on it was created in six literal days *does* conflict with evolutionary theory); however, most religious groups have no conflict with the theory of evolution or other scientific findings. In fact, many religious people, including theologians, feel that a deeper understanding of nature actually enriches their faith. Moreover, in the scientific community there are thousands of scientists who are devoutly religious and also accept evolution. For concise statements from many religious organizations regarding evolution, see Voices for Evolution on the NCSE website. To learn more about the relationship between science and religion, visit the Understanding Science website.

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2.5: Critical Thinking

Critical Thinking: A Fundamental Human Skill

Think about the last time you had a heated debate with someone—maybe about politics, sports, or even whether the carnivore or vegan diet was best. Did you find yourself getting defensive? That's natural. But here's a key truth about critical thinking: your own worldview (the lens through which you see everything) can actually get in the way of thinking clearly and fairly. To be fair-minded, you need to be willing to seriously consider viewpoints that oppose your own. In simpler terms: *you have to be willing to admit you might be wrong*.



Figure 2.5.1:Worldviews act as the lenses through which we see the world. Photo by Sagar Kulkarni on Unsplash

We can't give our own worldview a free pass. Instead, we need to recognize that our worldview probably contains prejudices, biases, and perhaps even mistaken beliefs. Everything we experience or remember is filtered through the set of beliefs and values that make up our worldview. The term "**worldview**" refers to the framework we use to interpret the world around us. A first step toward critical thinking is recognizing just how important these frameworks are in shaping our perspectives and those of others. As philosopher Ken Wilber explains:

"What our awareness delivers to us is set in cultural contexts and many other kinds of contexts that cause an interpretation and a construction of our perceptions before they even reach our awareness. So what we call real or what we think of as a given is actually constructed—it's part of a worldview."

Worldviews are like incredibly powerful filters that shape how we relate to everything around us and how we make sense of life itself. Indeed, the center of any worldview is a core conviction or set of convictions about the nature of what is real, true, and important (Phipps 2012:24). Worldviews are deeply embedded not only in our brain and sense of self, but also within the culture (family, school, community, state, nation) in which we live. Because worldviews are so deeply embedded, we often take them for granted—we don't even realize they're there, shaping everything we think and feel.

To think critically is to be willing to examine conflicting positions fairly and accept that even lifelong beliefs might be wrong. Developing analytical skills—like comparing and contrasting ideas—is an important step, but that's just applying critical thinking *skills*. True critical thinking (the "strong sense") requires both skills *and* the right attitude: a disposition toward fair-mindedness plus awareness of the emotional, cognitive, and perceptual biases that distort our judgment. You can use critical thinking skills just to win arguments and defend what you already believe—and that's fine—but real critical thinking is much more than that. Below are the attributes and practices of a strong critical thinker.

The Critical Thinking Attitude: Staying Open-minded and Curious

- **Intellectual humility** - a willingness to admit error, change beliefs when warranted, or suspend judgment
- **Confidence in reason** - a willingness to go wherever the evidence leads
- **Intellectual curiosity** - a love of exploring new topics, learning new things, and gaining knowledge
- **Intellectural independence** - a willingness to honestly and fairly examine the positions of those you disagree with, and a willingness to question authority, tradition, and majority opinion

This critical thinking attitude doesn't come naturally—it must be cultivated. To understand this requires recognizing that there are a number of emotional, cognitive, and perceptual biases that influence how we interpret the world. Examining the assumptions we bring to any set of issues, ideas, or experiences is a necessary component of critical thinking.

Another important component in developing critical thinking skills is reflecting on the effects of **egocentrism** and **ethnocentrism** on our ability to think critically. Each of us evaluates what we perceive, read, or hear through the filter of our worldview, and most of us tend to measure anything new by what we already believe and feel. We tend to think that we understand our own experience better than anyone else ever could (egocentrism). However, because of emotional biases, including the need to feel safe and certain in our beliefs, we tend to interpret our experiences in a way that's consistent with our worldview rather than open ourselves to other possibilities. Critical thinking demands a kind of reflective thinking that includes subjecting your own worldview to the same kind of scrutiny and critical analysis that you're willing and able to apply to the worldviews of those who don't think like you do (Grant 2021:60).

The Limits of Socio-centric Thinking

Most of us don't fully recognize the degree to which we've uncritically internalized the dominant prejudices of our society or culture (ethnocentrism). Sociologists and anthropologists call this being "culture bound." This phenomenon is caused by socio-centric thinking, which includes:

- The uncritical tendency to place one's culture, nation, and/or religion above all others
- The uncritical tendency to select self-serving positive descriptions of ourselves and negative descriptions of those who think differently
- The uncritical tendency to internalize group norms and beliefs, take on group identities, and act as we're expected to act---without the least sense that what we're doing might reasonably be questioned
- The tendency to unquestioningly conform to group restrictions (many of which are arbitrary or coercive)
- The failure to think beyond the prejudices of one's own culture
- The failure to study and internalize the insights of other culture (thereby limiting the breadth and depth of one's thinking)
- The failure to distinguish universal ethics from relativistic cultural requirements and taboos
- The failure to realize that mass media in every culture shapes the news from that culture's point of view
- The failure to think evolutionarily – historically and anthropologically – (and thus to be trapped in current ways of thinking)
- The failure to see socio-centric thinking as a significant impediment to intellectual development

In other words, socio-centric is incredibly limiting. To counter this requires using cross-cultural, fair-minded thinking---critical thinking in the strong sense.

With this in mind, critical thinking is a disposition to use our critical thinking skills all the time for any subject. One way to develop critical thinking skills is to cultivate a practice of critically examining the presuppositions of your own culture as expressed in social media, news outlets, textbooks, political speeches and policies, and in the personal values and beliefs you've accumulated over the years.

Here are some tips to develop critical thinking skills with respect to politics, although these could easily be applied to nearly any subject or issue:

1. Get multiple viewpoints. Read or listen to people on the right, the left, and in the middle.

2. Find a role model you trust who has a reputation for courage and honesty and isn't always towing the party line.

3. Surround yourself with people who like vigorous conversation rather than shouting matches.

4. Don't be afraid to suspend judgment at times. You don't always have to have an opinion on every hot-button issue that

comes down the pike. It's perfectly okay to say, "I don't know."

5. Be a skeptic but not a cynic. Don't be afraid to doubt claims made without support. Ask questions, but don't stereotype politicians or journalists. Don't assume that they're all liars or intentionally biased. Don't be gullible. Make others provide reasons and evidence for their claims. The skeptic says, "That doesn't sound right to me. Show me the evidence." The cynic says, "You politicians and journalists are all liars. I don't trust anything you say."

The ultimate goal of developing and using critical thinking, and of becoming a critical thinker, is to make informed, unbiased decisions about personal, civil, national, global, and scientific issues that affect human beings and the world in which we live. Use this insight and keep it in mind as you're exposed to the rich and broad array of knowledge and information about the world that a liberal arts education provides.



Figure 2.5.2:Keeping an open mind is essential for critical thinking. Photo by Júnior Ferreira on Unsplash

"Between accepting everything others tell you or rejecting everything and withdrawing, there is the middle ground of critically evaluating information and constructing your own opinion" — Michael Hale (speaking about arguments around immigration)

"We are drowning in information, while starving for wisdom. The world henceforth will be run by synthesizers, people able to put together the right information at the right time, think critically about it, and make important choices wisely." — E.O. Wilson, Biologist

Questions for Your Own Reflection

In conclusion, take a moment to critically reflect on the following questions. Record your thoughts in your notebook, journal, or digital file and return to them from time to time to remind yourself of both the value in critical thinking and the growth you experience as your thinking expands and evolves.

1. Think about an issue you're really passionate about. What experiences, viewpoints, and information have shaped the way you think about this issue? Are you aware of any opposing viewpoints? Have you taken the time to investigate and weigh those opposing viewpoints? If so, did it strengthen your original position on the issue, or did it cause you to be more open-minded about your own and others' perspectives?

2. Have you ever felt strongly about a certain issue and then learned more about it and changed your mind about how you felt? What did you learn from this experience?

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2.6: Key Terms

adaptation - A feature produced by natural selection for its current function

allele - One of the versions of a gene that may exist at a locus on a chromosome. For example, the pea color locus may have either the yellow allele or the green allele. Different alleles of the same locus are often symbolized by capital and lowercase letters (e.g., the Y and y alleles).

development - Change in an organism over the course of its lifetime; the processes through which a zygote becomes an adult organism and eventually dies

gene - The unit of heredity. Generally, it means a region of DNA with a particular phenotypic effect. Technically, it may mean a stretch of DNA that includes a transcribed and regulatory region.

genetic drift - Random changes in the gene frequencies of a population from generation to generation. This happens as a result of sampling error — some genotypes just happen to reproduce more than other genotypes, not because they are "better," but just because they got lucky. This process causes gene frequencies in a population to drift around over time. Some genes may even "drift out" of a population (i.e., just by chance, some gene may reach a frequency of zero). In general, genetic drift has the effect of decreasing genetic variation within a population.

genetic variation - the amount of genetic diversity (difference) there is within populations or species. Genetic variation is essential for natural selection to operate since natural selection can only increase or decrease the frequency of alleles (different forms of a gene) already in the population.

migration - The movement of individuals between populations.

mutation - A change in a DNA sequence, usually occurring because of errors in replication or repair. Mutation is the ultimate source of genetic variation

natural selection - Differential survival or reproduction of different genotypes in a population leading to changes in the gene frequencies of a population. The conditions required for the operation of evolution by natural selection include variation, inheritance, differential reproduction, and time.

population - Generally, a group of organisms living close to one another that interbreed with one another and do not breed with other similar groups; a gene pool. Depending on the organism, populations may occupy greater or smaller geographic regions.

random - Unpredictable in some way. Mutations are "random" in the sense that the sort of mutation that occurs cannot generally be predicted based upon the needs of the organism. However, this does not imply that all mutations are equally likely to occur or that mutations happen without any physical cause. Indeed, some regions of the genome are more likely to sustain mutations than others, and various physical causes (e.g., radiation) are known to cause particular types of mutations.

taxon - (taxa — plural) Any named group of organisms (e.g., the reptiles, Felidae, beetles, *Homo sapiens*)

theory - A broad explanation for a wide range of phenomena. Theories are concise, coherent, systematic, predictive, and broadly applicable. They usually integrate many individual hypotheses. A scientific theory must be testable with evidence from the natural world. If a theory can't be tested with experimental results, observation, or some other means, then it is not a scientific theory.

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3: NATURAL SELECTION

Learning Objectives

- Identify and describe the historical development of evolutionary thought.
- Summarize the key experiences and evidence that shaped Darwin's thinking.
- Distinguish the scientific theory of natural selection from Social Darwinism and explain why conflating the two is a common but serious error.
- Explain the logical chain of natural selection and describe how these conditions together produce evolutionary change.
- Apply the logic of natural selection to examples outside of biology.
- Identify and correct common misconceptions about natural selection.

3.1: A Brief History of Evolutionary Thought

3.2: The Journey to Natural Selection

3.3: Natural Selection

3.4: Evidence

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3.1: A Brief History of Evolutionary Thought

> ***"Ideas also form in an environment. They require a foundation of previous ideas, the availability of raw information, and a society that supports new thinking."*** ~ Mark Sumner, author of *The Evolution of Everything: How Selection Shapes Culture, Commerce, and Nature*.

Long before anyone used the term "evolution," people were paying close attention to the living world around them. Survival depended on it. Early humans needed to know which plants could heal and which could kill, where the closest and safest water source was, how other animals behaved, and how the seasons turned. Indigenous peoples of the Americas, and the scholars of ancient Mesopotamia and Egypt, left behind detailed records of this knowledge in stories, hieroglyphics, and oral traditions (Dunbar-Ortiz 2014; Moore 1993). The habit of observing nature closely and asking why it looks the way it does is not a Western invention — it's a human one, thousands of years in the making.

By the time Charles Darwin was born in 1809, more than two thousand years of recorded thought about the natural world had already accumulated. Rather than walking through every thinker who contributed to that record, this section highlights a handful of foundational ideas that served as the building blocks that eventually made Darwin's explanation, or theory, possible.

The World Was Already Watching

The Greek philosopher Aristotle (384-322 BCE) was among the first to insist that the natural world could be understood through direct observation rather than divine explanation. He dissected animals, interviewed beekeepers and fishermen, and classified nearly 500 species based on their structure, reproduction, and behavior (Moore 1993). This begins to lay the foundation for nature as something to be studied, not simply accepted.

Aristotle also ranked living things in a **hierarchy,** placing animals above plants, live-bearing animals above egg-layers, and so on. Medieval scholars later expanded this into the ***Scala Naturae***, or "Great Chain of Being," a ladder of life with God at the top and minerals at the bottom, with humans placed just beneath the angels. This idea of "higher" and "lower" organisms shaped Western thinking for well over a thousand years, and it still lingers strongly today whenever someone describes an animal as "more evolved" than another (as we'll see later, evolution doesn't actually work that way).

Evolutionary thinking was never confined to Europe. The Islamic scholar Al-Jahiz (776-868 CE) built on Aristotle's work in his seven-volume Book of Animals, describing over 350 species. Centuries before Darwin, Al-Jahiz wrote about animals competing for resources and mates, and about environments pushing organisms to develop new traits that could be passed to their offspring (Love 2020). He described a genuine "struggle for existence" shaping which animals survived (Masood 2009). These ideas traveled through Islamic scholarship into medieval European universities via translations of Aristotle (Lindberg 1992), a reminder that the road to Darwin ran through many cultures, not a straight line through Western Europe alone.

The Tools Science Needed First

Before anyone could explain how species change, scientists needed some basic tools. Francis Bacon (1561-1626) helped establish the scientific method: the idea that claims about nature should be tested against careful observation, not settled on authority alone. John Ray (1627-1705) offered one of the first working definitions of a species. Carl Linnaeus (1707-1778) gave the world binomial nomenclature, the two-part naming system (genus and species) still used today, along with a systematic way to organize the sheer diversity of life. And Georges-Louis Leclerc, Comte de Buffon (1707-1788), popularized comparative anatomy, comparing body structures across species, and was among the first prominent naturalists to suggest that species themselves might change over time.

Does the Earth Have Enough Time?

For evolution to happen gradually, the Earth needs to be old, really old. This became one of the fiercest debates in science. Georges Cuvier (1769-1832) proved that species that had once roamed the earth had gone extinct by studying fossils of animals

with no living counterparts. He argued that species themselves never changed, but instead, catastrophic floods wiped out life in a region, which was then repopulated from elsewhere. This view, called **catastrophism**, fit neatly within a Bible-based timeline suggesting the Earth was only about 6,000 years old.

Geologists James Hutton (1726-1797) and Charles Lyell (1797-1875) argued the opposite: that the same slow, ordinary processes we see today—erosion, sedimentation, volcanic activity—have been shaping the Earth for an immense span of time, an idea known as **uniformitarianism**. Lyell's guiding principle, "the present is the key to the past," meant that ripples in ancient sandstone could be explained by watching ripples form in sands today, just multiplied across millions of years. Lyell became a close friend of Darwin's, and his three-volume Principles of Geology (1830-1833) gave Darwin exactly the kind of "deep time" his theory of gradual change would eventually require.

A First (Wrong) Mechanism, and a Missing Piece

Jean-Baptiste Lamarck (1744-1829) deserved credit for a genuine breakthrough: he was the first scientist to propose an actual mechanism for how species change, and to recognize that the environment plays an active role in shaping organisms. His theory, the **inheritance of acquired characteristics**, held that traits acquired through use during an individual's life could be passed on directly to that individual's offspring.

Lamarck's theory involved a three-step process. In step one, an animal experiences a radical change in its environment. In step two, the animal (either individual or species) responds with a new kind of behavior. In step three, that behavioral change results in morphological (meaning physical) changes to the animal, which are then successfully passed on to subsequent generations (Ward 2018, 8). Lamarck's most famous example was the proposition that giraffes actively stretched their necks to reach leaves on tall trees to eat. Over their lifetimes, the continuation of this habit resulted in gradual lengthening of the neck. The

How giraffes actually ended up with long necks is a different story. In an environment where the food supply is higher off the ground, and perhaps less available to competing species, giraffes who happened to have slightly longer necks (due to random individual variation and genetic mutation) would be more likely to survive. These giraffes would then be able to reproduce, passing along the slight variation in neck length that would allow their offspring to do the same. Over time, individuals with longer necks would be overrepresented in the population, and neck lengths overall would increase among giraffes.

> **The Evolution of Long Necks in Giraffes**
>
> By **Douglas R. Cavener**, Huck Distinguished Chair in Evolutionary Genetics and Professor of Biology, Penn State
>
> Everything in biology ultimately boils down to food and sex. To survive as an individual you need food. To survive as a species you need sex.
>
> Not surprisingly then, the age-old question of why giraffes have long necks has centered around food and sex. After debating this question for the past 150 years, biologists still cannot agree on which of these two factors was the most important in the evolution of the giraffe's neck. In the past three years, my colleagues and I have been trying to get to the bottom of this question.



Figure 3.1.1: These three giraffes in Masai Mara National Park exhibit different neck lengths based on age and sex. Image by Byrdyak, CC BY-SA 4.0 via Wikimedia Commons.

Necks for sex

In the 19th century, biologists Charles Darwin and Jean Baptiste Lamarck both speculated that giraffes' long necks helped them reach acacia leaves high up in the trees, though they likely weren't observing actual giraffe behavior when they came up with this theory. Several decades later, when scientists started observing giraffes in Africa, a group of biologists came up with an alternative theory based on sex and reproduction.

These pioneering giraffe biologists noticed how male giraffes, standing side by side, used their long necks to swing their heads and club each other. The researchers called this behavior "neck-fighting" and guessed that it helped the giraffes prove their dominance over each other and woo mates. Males with the longest necks would win these contests and, in turn, boost their reproductive success. That favorability, the scientists predicted, drove the evolution of long necks.



Figure 3.1.2: Neck fighting giraffes (*Giraffa camelopardalis*) in Ithala Game Reserve, Northern KwaZulu Natal, South Africa. Image by Luca Galuzzi (Lucag), CC BY-SA 2.5 via Wikimedia Commons.

Since its inception, the necks-for-sex sexual selection hypothesis has overshadowed Darwin's and Lamarck's necks-for-food hypothesis.

The necks-for-sex hypothesis predicts that males should have longer necks than females, since only males use them to fight, and indeed they do. But adult male giraffes are also about 30% to 50% larger than female giraffes. All of their body components are bigger. So my team wanted to find out if males have proportionally longer necks when accounting for their overall stature, comprised of their head, neck and forelegs.

Necks not for sex?

But it's not easy to measure giraffe body proportions. For one, their necks grow disproportionately faster during the first six to eight years of their life. And in the wild, you can't tell exactly how old an individual animal is. To get around these problems, we measured body proportions in captive Masai giraffes in North American zoos. Here, we knew the exact age of the giraffes and could then compare this data with the body proportions of wild giraffes that we knew confidently were older than 8 years.

To our surprise, we found that adult female giraffes have proportionally longer necks than males, which contradicts the necks-for-sex hypothesis. We also found that adult female giraffes have proportionally longer body trunks, while adult males have proportionally longer forelegs and thicker necks.

Giraffe babies don't have any of these sex-specific body proportion differences. They only appear as giraffes are reaching adulthood.

Finding that female giraffes have proportionally both longer necks and longer body trunks led us to propose that females, and not males, drove the evolution of the giraffe's long neck, and not for sex but for food and reproduction. Our theory is in agreement with Darwin and Lamarck that food was the major driver for the evolution of the giraffe's neck, but with an emphasis on female reproductive success.

A shape to die for

Giraffes are notoriously picky eaters and browse on fresh leaves, flowers and seed pods. Female giraffes especially need enough to eat because they spend most of their adult lives either pregnant or providing milk to their calves.

Females tend to use their long necks to probe deep into bushes and trees to find the most nutritious food. By contrast, males tend to feed high in trees by fully extending their necks vertically. Females need proportionally longer trunks to grow calves that can be well over 6 feet tall at birth.

For males, I'd guess that their proportionally longer forelegs are an adaptation that allows them to mount females more easily during sex. While we found that their necks might not be as proportionally long as females' necks are, they are thicker. That's probably an adaptation that helps them win neck fights.

But giraffes' necks aren't their only long feature. They have very long legs, proportionally, which contribute to their height almost as much as their necks. Their long legs come at a considerable cost, though – particularly for male giraffes. A disproportionate fraction of their body mass is stacked on top of their spindly front legs, which can lead to injury and mobility issues in the long run.



Figure 3.1.3: Giraffes are the tallest terrestrial mammal. Image by AfricanConservation, CC BY-SA 4.0 via Wikimedia Commons.

Graham Mitchell, a prominent giraffe biologist, has called the giraffe body "a shape to die for." In captivity, where staff can determine the cause of death, well over half of male giraffes die from foreleg problems, which shortens their lifespan by 25% compared with females. Very few female giraffes die from health issues related to their legs.

Giraffes' height also means they can't climb up steep slopes very well. My team's research has shown that this limitation has likely stopped them from traveling across the escarpments of the Great Rift Valley in East Africa. But the mating advantage from being tall must outweigh these costs to their health and mobility.

This research isn't ruling out the necks-for-sex theory entirely. The long neck likely does play a critical role in male neck-fighting and winning a mate. But our research suggests that male neck-fighting was probably a side benefit that came along with females getting better access to food.

In the future, my team will look into the genetic factors that led to the giraffe's extraordinary stature and physique. We want to trace and reconstruct the evolutionary path they took to reach toward the skies.

Source: Cavener, D. (2024, June 5). Female giraffes drove the evolution of long giraffe necks in order to feed on the most nutritious leaves. *The Conversation*. https://theconversation.com/female-giraffes-drove-the-evolution-of-long-giraffe-necks-in-order-to-feed-on-the-most-nutritious-leaves-new-research-suggests-227029

Lamarck had the right instincts but the wrong mechanism. We know a bodybuilder's children aren't born muscular. Acquired traits simply don't get passed on this way. Interestingly though, modern epigenetics has shown that some life experiences — chronic stress, poor nutrition, toxin exposure — really can leave chemical marks on gene expression that get passed to offspring. It's a fascinating and fast-growing area of research we'll return to later, but it works through very different mechanisms than Lamarck imagined.

The final piece came from someone who wasn't a naturalist at all. Thomas Malthus (1766-1834), an English economist, published *An Essay on the Principles of Population* in 1798, arguing that populations naturally grow faster than their food supply, a concept still used today as **carrying capacity**. In Malthus's England, this played out as poverty and overcrowding during the Industrial Revolution; in nature, Malthus argued, the same math applies to every species. Some individuals will always be born who don't survive to reproduce. Malthus never intended his idea for biology, but it became the missing piece Darwin needed.

By the 1850s, then, science had assembled most of the picture: an ancient Earth (Hutton, Lyell), evidence that species really do change and go extinct (Cuvier, Buffon), and a reason why not every individual survives (Malthus). What remained unanswered was the question this chapter is really about: out of all the individual variation in a population, what determines which traits get passed on and which don't? That answer would come from one of the greatest synthesizers and systems thinkers of his time, a naturalist named Charles Darwin.

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3.2: The Journey to Natural Selection

> ***"[Darwin] accepted that Nature was always going to be smarter, stronger, and swifter than any old naturalist, himself included."*** ~ Kay Harel, author of *Darwin's Love of Life: A Singular Case of Biophilia*.

Charles Darwin is one of the most immediately recognizable men who ever lived. Many people are familiar with the iconic image of him in his later years, with a long beard and deep-set eyes. Over 160 years after he published his most famous work, *On the Origin of Species*, which outlined his theory of biological evolution through natural selection, his name still provokes heated debate, thoughtful discussion, heartfelt praise, and utter contempt.

Yet the ideas that made Darwin famous have been heavily misunderstood, and that was true even before those ideas ever appeared in print (Sumner 2010:5).

Who Was Charles Darwin?

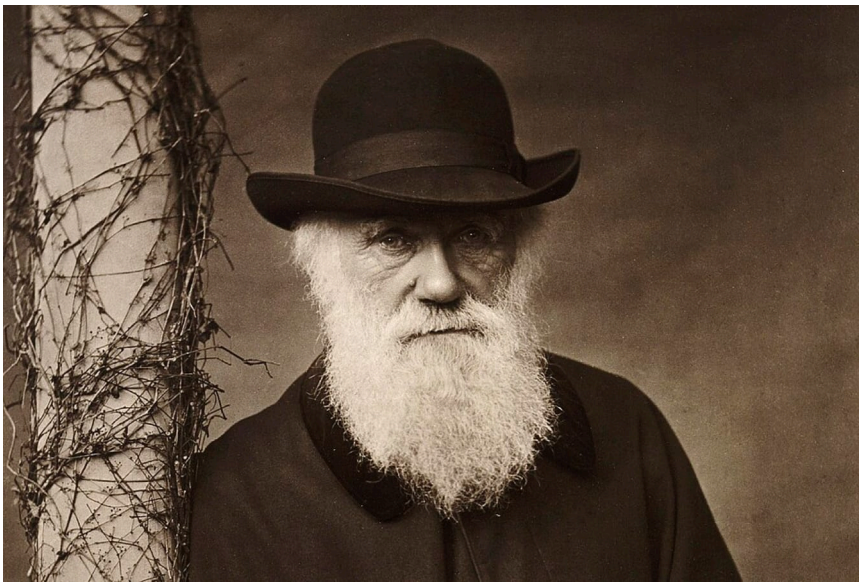


Figure 3.2.1: The great naturalist, Charles Darwin. Image credit: Elliott & Fry, Public domain, via Wikimedia Commons.

It's worth pausing on Darwin as a person before turning to Darwin the scientist because the two are hard to separate. Born in 1809 into a wealthy, well-connected English family, Darwin was, by his own account, an unremarkable student. He found medical school in Edinburgh unbearable and drifted through divinity studies at Cambridge with little enthusiasm. What he loved doing most of all was collecting beetles, hunting, and taking long walks in the countryside. He wasn't the era's brightest young star; he was something rarer—someone capable of sustained, patient curiosity, comfortable sitting with a question for decades rather than rushing to an answer.

It also matters that Darwin didn't invent the idea of evolution. By his time, as we've seen, it had already been circulating for millennia across multiple civilizations. What set Darwin apart was his ability to synthesize an overwhelming range of evidence, from geology to economics to pigeon breeding, into a single coherent explanation, and his willingness to keep testing that explanation against every new observation he could get his hands on for the rest of his life (Harel 2022; Sumner 2010).

Five Years at Sea (Mostly on Land)



Figure 3.2.2: Map of the voyage of the H.M.S. Beagle. Credit: Voyage of the Beagle-de by Succu is under a CC BY-SA 3.0 License.

In 1831, at age 22, Darwin joined the crew of the HMS Beagle as it set out to chart the coastline of South America. Darwin suffered from severe seasickness the entire voyage, so severe that of the nearly five years the expedition lasted, he spent only about a year and a half actually aboard the ship (Costa 2017). The rest of the time, he was ashore, and that turned out to be a scientific gift: it gave him unmatched time to explore, collect, and observe.

In Argentina, Darwin found fossils of extinct armadillos in the very same locations where living armadillos still roamed — a direct challenge to Cuvier's catastrophism, which held that extinct and living forms must be entirely separate species from separate creation events. Traveling along the South American coast, he also noticed that closely related species varied gradually from place to place, with populations that lived closer together looking more alike than those farther apart.

These patterns became unmistakable in the Galapagos Islands. Local residents told Darwin they could identify which island a giant tortoise came from just by looking at the shape of its shell. Darwin noticed the same island-by-island variation among the islands' finches. Something was clearly happening here that the fixed, unchanging categories of the time couldn't explain.

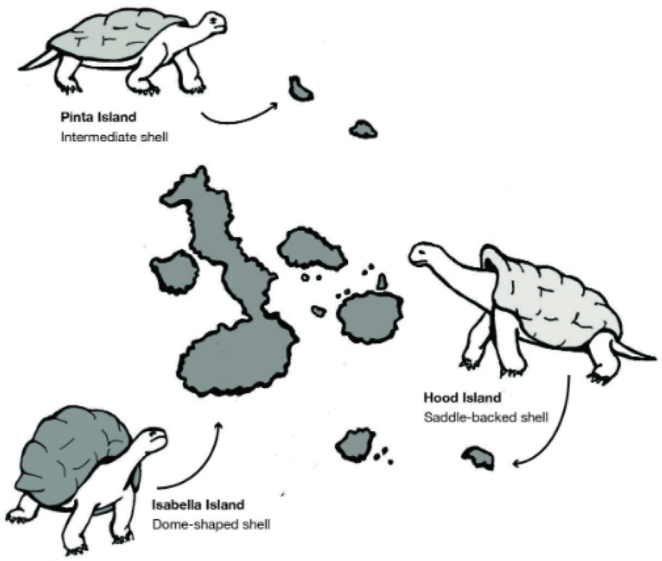


Figure 3.2.3: Variation in giant tortoises in the Galapagos Islands. Credit: Giant Tortoises of the Galapagos Islands original to Explorations: An Open Invitation to Biological Anthropology (2nd ed.) by Mary Nelson and Katie Nelson is under a CC BY-NC 4.0 License.

Twenty Quiet Years at Down House

Darwin knew exactly how risky these ideas were. Lamarck had been discredited and harassed for his theory of species change. Even Charles Lyell, Darwin's close friend, rejected the idea that species could change at all. So instead of rushing into print, Darwin spent roughly two decades after returning to England quietly gathering evidence at Down House, his family home for over forty years.

Down House essentially became a working laboratory. At various points, the hallways held trays of frog eggs, sixteen breeds of pigeons cooed in the yard, jars of seeds floated in saltwater in the cellar, and the smell of dissected pigeon skeletons filled the air. Darwin even recruited his son William to help him test whether plant seeds could survive an ocean crossing. They filled a bathtub with salt water, dropped in seeds of different plants, and checked every day to see which ones stayed afloat, and whether the ones that sank could still sprout, which, remarkably, most could (Sumner 2010). It's a small, homemade experiment, but it's a perfect example of how Darwin worked: turning a genuinely testable question — in this case, how plants and animals might have colonized remote islands separated from the mainland by vast stretches of ocean — into a hands-on experiment, using whatever was on hand.

This picture of Darwin's patient, methodical approach is worth sitting with, because it's easy to imagine scientific discovery as a single lightning-bolt moment — a flash of genius, all at once. Darwin's breakthrough looked nothing like that. It looked like decades of repetitive observation with one small notice adding to the next, until a pattern the size of a theory finally came into view. That kind of noticing isn't reserved for scientists. Anyone can watch which weeds continue to pop up after being mowed and which don't or which birds get the feeder first and which get pushed aside. The raw material of science is often just about paying attention long enough, and closely enough, to see what was there all along.

Did You Know? How One Species Becomes Many



Figure 3.2.4: The eastern coast of the island of Kaua'i. Image by Farragutful, CC BY-SA 4.0 via Wikimedia Commons.

Kaua'i was formed by a volcano roughly five million years ago. As the oldest of the main Hawaiian Islands, it has had the most time to accumulate stray seeds carried in by wind, water, and animals — the same kind of long-distance colonization Darwin tested with his floating seed experiment at Down House. Whenever a new seed took root in the island's soil, the resulting plant sometimes evolved into an entirely new species, or often several, each adapted to a different niche within Kaua'i's favorable climate. This process, in which a single ancestral species diversifies into many descendant species, is known as **adaptive radiation** and is the same phenomenon Darwin observed among the Galápagos finches. In Kaua'i, the result has been thousands of plant varieties descended from just a handful of original colonizers, many of them endemic to the island, meaning they're found nowhere else on Earth (Schlanger 2024:29).



Figure $3.2.5a-b$: a) Kokiʻo keʻokeʻo or Kauai white hibiscus Malvaceae Endemic to the Hawaiian Islands (Kauaʻi only) and b) the Kokiʻo ʻula or St. John's hibiscus Malvaceae (Mallow family) Endemic to the Hawaiian Islands (Kauaʻi) IUCN: Endangered. Image by a) David Eickhoff from Pearl City, Hawaii, USA, CC BY 2.0 via Wikimedia Commons and b) David Eickhoff from Hawaiʻi, USA, CC BY 2.0 via Wikimedia Commons.

The Letter That Changed the Timeline

Darwin might have continued gathering evidence indefinitely if not for a letter that arrived in June 1858 from Alfred Russel Wallace, a naturalist working independently in Malaysia. Wallace had arrived at strikingly similar conclusions and asked Darwin to review his paper and pass it along to their mutual colleagues Charles Lyell and Joseph Hooker. Rather than let Wallace publish alone, Lyell and Hooker arranged for a joint reading of both men's work at the Linnean Society in England on July 1, 1858. Darwin's own book, *On the Origin of Species*, followed fifteen months later in November 1859.

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3.3: Natural Selection

Darwin never actually used the word “evolution” as his primary term. Instead, he called it *descent with modification*, meaning that all living things share common ancestors, but each generation differs slightly from the one before. Anyone who has looked closely at a litter of puppies or a row of seedlings has seen this in action: no two offspring look exactly like their parents, or like each other.

Reasoning from Farms to Nature

To explain why some of these small differences stick around across generations while other disappear, Darwin turned first to something very familiar: animal and plant breeding, or artificial selection. At Down House, he bred pigeons obsessively, tracking small physical differences across generations. In every case, breeders were selecting individuals with traits humans wanted, whether that was sweeter fruit, a particular color pattern, a faster gait, and breeding those individuals again and again. Small changes, repeated over many generations, added up to dramatic ones.

Darwin’s insight was that nature does something very similar, it just doesn’t require a human breeder. Instead of a farmer choosing which individuals reproduce, the environment does the choosing: heat, cold, predators, disease, food availability, and today, human-caused climate change all determine which individuals survive long enough to pass on their traits.

Artificial Selection

Long before Darwin and Wallace, people were using selection to change the features of plants and animals. Farmers and breeders allowed only the plants and animals with desirable characteristics to reproduce, causing the evolution of farm stock. This process is called **artificial selection** because people (instead of nature) select which organisms get to reproduce.

As shown below, farmers have cultivated many crops from wild mustard by artificially selecting for certain attributes.

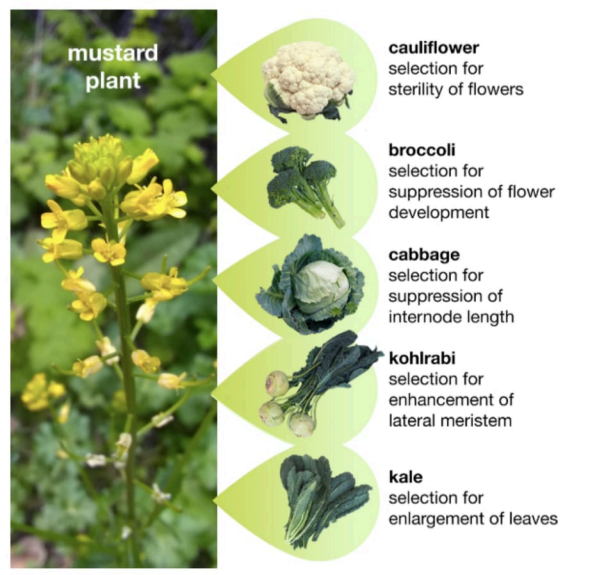


Figure 3.3.1: This diagram illustrates artificial selection in *Brassica oleracea* (wild mustard). On the left is a photo of the wild mustard plant. On the right, are five common vegetables, each paired with the specific trait humans selected for to produce it. Image credit (see below).

Source: *Artificial Selection*. Understanding Evolution. (June 2024) © UC Museum of Paleontology Understanding Evolution, www.understandingevolution.org is licensed under a Creative Commons CC BY-NC-SA 4.0 including images: Mustard photo courtesy of Pat Holroyd, all other brassica courtesy of Helina Chin.

The Logic of Natural Selection

The argument for natural selection basically comes down to a short chain of observations, each one building on the last:

First, overproduction: Every species produces many more offspring than its environment can support. **Second, variation**: Individuals within any population differ from one another in countless small, heritable ways. **Third, limited survival**: because resources are limited, not every individual survives to reproduce. **Fourth, differential reproductive success**: individuals whose traits happen to suit their particular environment are more likely to survive and reproduce. This is what biologists mean by **fitness**, and it has nothing to do with strength or intelligence in any general sense. **And fifth, inheritance**: because those individuals leave more offspring, their traits become more common in the population over time, while less advantageous traits become rarer. Repeated across enough generations, this process can produce populations, and eventually species, quite different from their ancestors.

Natural Selection in a Nutshell

Natural selection is one of the basic mechanisms of evolution, along with mutation, gene flow, and genetic drift.

Darwin's grand idea of evolution by natural selection is relatively simple but often misunderstood. To see how it works, imagine a population of beetles:

There is variation in traits. For example, some beetles are green and some are brown.



Figure 3.3.2: The variation shown here is in coloration. Some beetles are green, one is brown, showing the differences between individuals of the same species.

There is differential reproduction. Since the environment can't support unlimited population growth, not all individuals get to reproduce to their full potential. In this example, green beetles tend to get eaten by birds and survive to reproduce less often than brown beetles do.



Figure 3.3.3: The selective pressure applied here is the bird eating the less camouflaged green beetles.

There is heredity. The surviving beetles (more of which are brown) have offspring of the same color because this trait has a genetic basis.

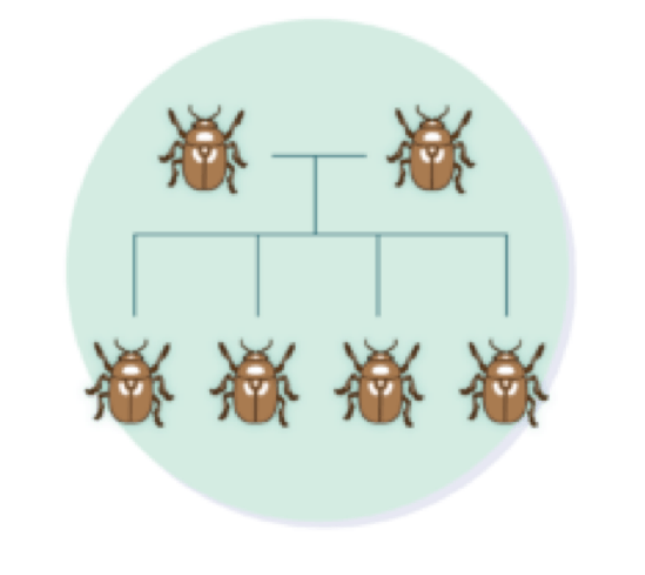


Figure 3.3.4: Two brown beetle parents produce even more brown beetle offspring.

End result: The more advantageous trait, brown coloration, which allows the beetle to have more offspring, becomes more common in the population. If this process continues, eventually, all individuals in the population will be brown.

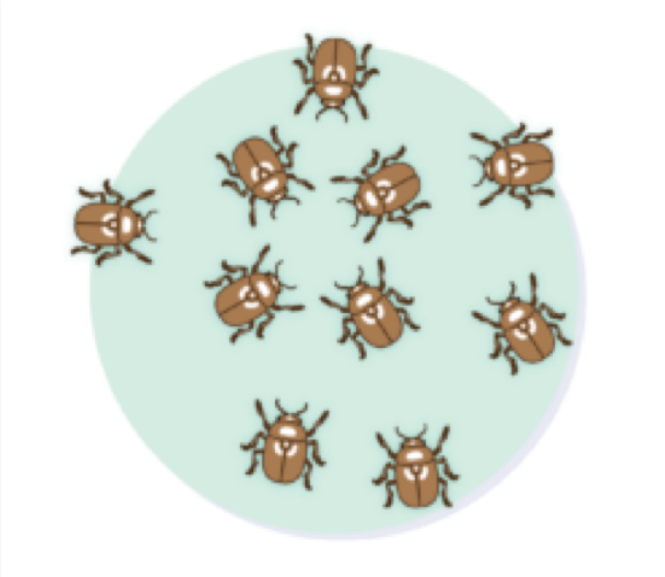


Figure 3.3.5: Ending population contains all brown beetles due to the differential reproductive success of the beetles with this trait.

If you have ***variation***, ***differential reproduction***, and ***heredity***, you will have evolution by natural selection as an outcome. It's as simple as that.

Source: *Natural Selection*. Understanding Evolution. (June 2024) © UC Museum of Paleontology Understanding Evolution, www.understandingevolution.org is licensed under a Creative Commons CC BY-NC-SA 4.0 license including images.

One distinction is worth being precise about: natural selection acts on individuals, but evolution happens to populations. An individual doesn't evolve during its lifetime, it either survives and reproduces, or it doesn't. It's the shifting balance of traits across the whole population, generation after generation, that we call evolution.

It's also worth being clear about what "fit" does *not* mean. Natural selection doesn't select for bigger, stronger, or more complex. It simply selects for whatever happens to work in a particular environment at a particular moment, and that can just as easily favor smaller or simpler organisms. When an asteroid ended the age of the dinosaurs roughly 66 million years ago, it wasn't the largest animals that had the advantage — it was small, unassuming mammals, a lineage that would eventually diversify into everything from bats to whales to primates, ourselves included.

"Lizard Island": A Case of Natural Selection in Action

A concrete example of natural selection in action that is still unfolding today come from a small island in a Miami lake, nicknamed "Lizard Island" by the biologists who study it. Researchers have spent over a decade tracking five species of anole lizards, measuring leg length, bite force, and sprint speed in the same population year after year. For years, brown anoles with fairly average-sized legs survived best. Then, a new species—a larger, more aggressive crested anole—arrived on the island, and the rules changed almost overnight. The newcomer pushed resident brown anoles out of the trees and onto ground more often, where escaping predators meant sprinting, and sprinting favored longer legs. Within just a few generations, longer-legged brown anoles were outliving and out-reproducing their shorter-legged relatives. No lizard changed on purpose; the environment changed, and what counted as an advantageous trait changed right along with it. Because researchers were measuring this population continuously, they got to watch natural selection happen in real time, not reconstruct it after the fact from fossils, the way Darwin had to.

Stroud, J. (2025, May 25). Amid a Tropical Paradise Known as "Lizard Island," Researchers are Cracking Open Evolution's Black Box — Scientist at Work. *The Conversation*. https://doi.org/10.64628/AAI.yf7sdyjnm

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3.4: Evidence

Darwin didn't ask anyone to take natural selection on faith. He built his case on multiple independent lines of evidence, and each one still holds up under modern scrutiny.

Evidence from Geography

The Galapagos tortoises gave Darwin a clean natural experiment. Tortoises on larger islands with abundant, low-growing vegetation had shorter necks and dome-shaped shells, since their food was close to the ground. Tortoises on smaller, drier islands, where food was mainly tall cactus, had longer necks, longer front legs, and saddle-shaped shells that let them stretch upward to reach it. Different islands produced different selective pressures and different outcomes, all in populations that had descended from a shared ancestor. Darwin observed a similar pattern among the islands' finches, whose beak shapes varied with the food available on each island.

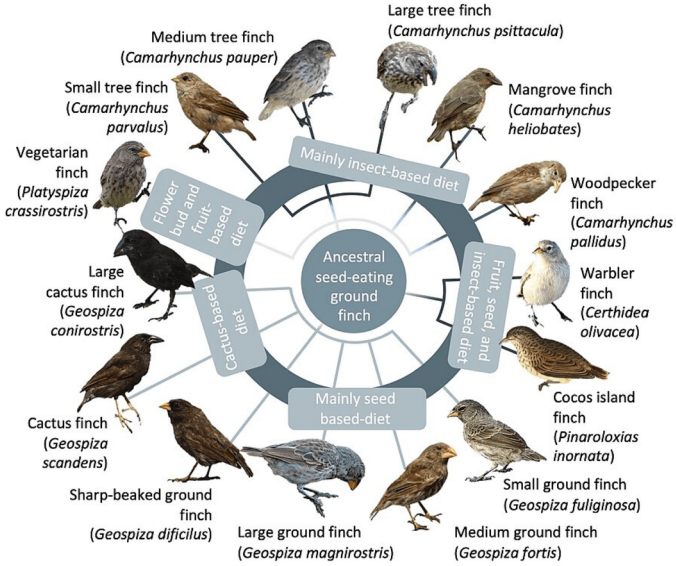


Figure 3.4.1: Galápagos finches differ in beak size and shape, depending on the type of food they eat. Image by: Bioanthropologist1, CC BY 4.0 via Wikimedia Commons.

Evidence from Fossils

The armadillo fossils Darwin found in Argentina, extinct forms buried in the same region where living armadillos still roamed, undercut the idea that living and extinct forms must always be unrelated, separately created species. Darwin acknowledged that the fossil record of his day was full of gaps, missing many of the transitional forms that would bridge ancient and modern species. Since then, advances in paleontology and geochronology (methods for dating rock and fossils) have filled in a great many of those gaps, and it is now well established that life is far older, and far more continuously connected across time, than Darwin himself was able to prove (Kutschera and Niklas 2004).

Evidence from Selective Breeding

Perhaps the most immediately visible evidence for the power of selection is one anyone can observe today: dog breeds. Every domestic dog, from a Chihuahua to a Great Dane, belongs to the same species, *Canis lupus familiaris*. They are all descended from wolves, reshaped almost entirely by human-directed selective breeding over the span of a few thousand years, which is a blink of an eye in evolutionary terms. If artificial selection can produce that much change on that short a timescale, it becomes far easier to imagine what natural selection can do over millions of years.



Figure $3.4.2a - d$: A variety of domestic dog breeds that are all the same species, *Canis lupus familiaris*. From left: a) a Chihuahua, Image by Manuela Federspiel from Pixabay; b) a French Bulldog, Image by Fabian Köhler from Pixabay; c) a Welsh Corgi Image by Andrey Muzychuk from Pixabay; d) a Great Dane Image by Martin Tajmr from Pixabay.

Evidence Darwin Never Saw

Darwin had no idea what a gene was. DNA wouldn't even be identified as the molecule of heredity for nearly a century after his death. Yet everything discovered since — genetics, molecular biology, the mapping of the human genome — has consistently supported and refined his framework rather than overturning it. We'll explore exactly how heredity works at the molecular level in the next chapter. For now, the important point is that an idea proposed with 19th century tools has held up remarkably well under 21st century scientific scrutiny.

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3.5: Origin of Species

When Darwin finally set his argument down in *On the Origin of Species* (1859), he described the book as "one long argument." In his own words,

> *"...as more individuals are produced than can possibly survive, there must in every case be a struggle for existence...owing to this struggle for life, any variation, however slight..., if it be any degree profitable to an individual..., will tend to the preservation of that individual, and will be inherited by its offspring...I have called this principle, by which slight variation, if useful, is preserved, by the term Natural Selection."* (Darwin 1859: 61-62).

Origin was just the beginning. Darwin went on to publish ten more books, applying the same patient, evidence-gathering approach to topics ranging from orchids to human emotion to earthworms (Harel 2022).

Reception, Distortion, and Ongoing Relevance

The book landed as both a scientific and a cultural earthquake. It challenged the idea that species were fixed since creation, and it challenged an idea that is nearly as prevalent today as it was in Darwin's time: human exceptionalism or the assumption that humans stand categorically apart from, and above, the rest of the animal kingdom. Darwin, by contrast, saw humans as one species among many, shaped by the same biological, natural processes as everything else alive.

Almost immediately, some of Darwin's contemporaries borrowed his language to justify social and political hierarchies that Darwin never argued for, much less agreed with, himself — a movement that came to be known as **Social Darwinism** (Sumner 2010). This is a genuinely important distinction for understanding the history of science. The biological theory of natural selection, which describes how traits spread in populations over generations, is a separate thing from the social and political ideologies that came to be associated with Social Darwinism. That confusion has never fully gone away. Even today, debates over Darwin's ideas in classrooms and public life often trace back to this same tangle between the science itself and the uses (and misuses) people have made of it.

The Evolution of Everything: Why This Still Matters to You



Figure 3.5.1: The evolution of mobile communication from the earliest, iconic "brick" mobile phone to the mini-computer smart phones we carry today. Image produced with Google Gemini.

The principles of natural selection—variation, competition for limited resources, and the differential survival of whatever happens to work—show up far beyond biology. Consider why the Toyota Prius and Honda Insight, released as competing hybrid cars in the late 2000s, ended up looking so similar. Both companies were solving the same problem under the same constraints, trying

to maximize interior space, minimize air resistance, and increase fuel efficiency. Unsurprisingly, they arrived at strikingly similar shapes. Biologists see the same pattern constantly in nature: unrelated species independently evolve similar solutions to similar environmental problems, a phenomenon called **convergent evolution**. Basically, in evolution, if something works well, nature tends to repeat itself using its best mechanisms, like natural selection, over and over and across the spectrum of life (Harel 2022; Schlanger 2024).

The same selective logic plays out in job markets that reward certain skills over others, in the design of the phone in your pocket, and in which businesses on a city block survive or fail. Anywhere that variation exists and resources are limited, something like selection is at work, favoring whatever happens to fit the current environment. That, more than the finches or the tortoises, is why an idea Darwin worked out almost 170 years ago hasn't gone anywhere. Understanding how it actually works gives you a powerful lens for making sense of the world you live in every day.

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3.6: Are We Still Evolving?

> ***"Nature is chaos in motion. Biological life is a spiraling diffusion of possibilities, fractal in its profusion."*** ~ Zoë Schlanger, author of *The Light Eaters: How the Unseen World of Plant Intelligence Offers a New Understanding of Life on Earth*.

After reading this chapter, many students are curious to know if humans are still evolving. The answer is yes. As a species, we continue to respond to selective pressures biologically and culturally. Let's consider an example you probably have some familiarity with.

Human wisdom teeth are undergoing evolutionary pressure. Have you or anyone in your family had their wisdom teeth removed? While it can be a painful and expensive process, it is a common experience in Western nations. It raises the question of why there is no longer room in our mouths for all of our teeth. Biological anthropologist Daniel Lieberman offers several reasons, including that modern humans are growing faster and maturing earlier, which could be leading to impaction if skeletal growth takes place faster than dental growth. He also argues that the soft diets many modern humans consume generate insufficient strain to stimulate enough growth in our jaws to accommodate all of our teeth. Lastly, as the human brain has expanded over the past hundreds of thousands of years, it is taking up more space in the skull, causing the jaw to shrink, leaving no room for third molars (Lieberman 2011).

Conversely, do you know anyone whose wisdom teeth never came in? That is fairly common in some populations, suggesting evolutionary pressure favoring the absence of wisdom teeth has been culturally influenced. The oldest fossil evidence of skulls missing third molars was found in China and is 300,000 to 400,000 years old, suggesting the earliest mutation selecting against the eruption of wisdom teeth arose in Asia (Main 2013). Since that time, jaws have continued to decrease in size to the point they often cannot accommodate third molars, which can become impacted, painful, and even infected, a condition physical anthropologist Alan Main argues might have interfered with the ability to survive and reproduce in ancestral populations (Main 2013).

As we have learned, a mutation that positively influences reproductive success—such as being born without the trait to develop wisdom teeth—would likely be selected for over time. Evidence in modern humans suggests that this is the case, with 40% of modern Asians and 45% of Native Alaskans and Greenlanders (populations descended from Asian populations) lacking wisdom teeth. The percentage among those of European descent ranges from 10 to 25% while the percentage for African Americans is 11% (Main 2013). Later chapters of this textbook emphasize that directional selection progresses along a particular path until the environment changes and a trait is no longer advantageous. In the case of wisdom teeth, the ability of modern dentistry to preempt impaction through surgery may, in fact, be what is preventing natural selection from doing away with wisdom teeth altogether.

We Contain Multitudes

Perhaps one of the most striking challenges to how we think about human evolution right now comes from rethinking what a human being actually is in the first place.

In his 2016 book, *I Contain Multitudes: The Microbes Within Us and a Grander View of Life*, science writer Ed Yong opens with a small glowing squid. The Hawaiian bobtail squid carries a special light organ that it fills, fresh every night, with a species of bioluminescent bacteria it recruits from the surrounding seawater. The bacteria glow, and the squid uses that glow to cancel out its own shadow in the moonlit water, hiding it from predators lurking below. In return, the bacteria get a warm, sugar-rich home they can't find anywhere else. Neither the squid nor the bacteria could pull this off alone, but together, they function less like two separate organisms sharing space and more like a single unit (Yong 2016).

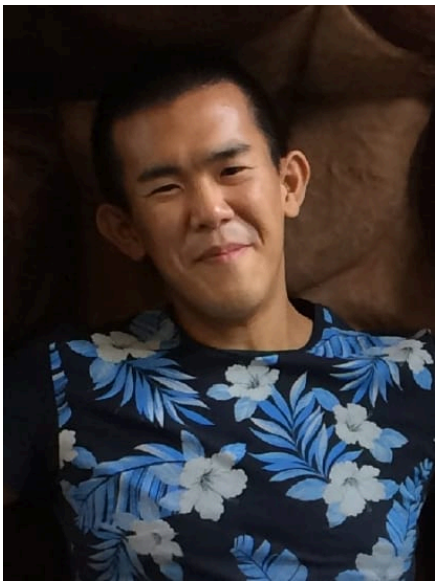


Figure 3.6.1: Science writer, Ed Yong, author of *I Contain Multitudes.* Image by Edyong209, CC BY-SA 4.0 via Wikimedia Commons.

The "single unit" idea has a name: the **holobiont,** a composite organism made up of a host together with all of its resident microorganisms. The term was popularized in the 1990s by Lynn Margulis, a pioneering evolutionary biologist who took the evolutionary role of bacteria seriously long before it became a focus in mainstream biology, at a time when most of her colleagues still treated microbes as background noise to the "real" business of evolution happening in plants and animals (Schlanger 2024:188). Margulis argued that partnerships like these may have shaped the history of life just as profoundly as the slow accumulation of random mutations that evolutionary biology traditionally emphasizes, and Yong's book makes that case accessible through examples across the animal kingdom: squid, beetles, wasps, and eventually, us. According to Yong, an average human body contains somewhere in the neighborhood of 30 trillion human cells and roughly 39 trillion microbial ones (Yong 2016). Depending on how you count, you are barely half "you." Bacteria, fungi, and other microorganisms, collectively called your **microbiome**, live on your skin, line your gut, and help train your immune system, digest your food, and, current research suggests, even influence your mood.

Remarkably, Darwin himself seemed to sense something like this nearly a century before anyone had the tools to prove it. In 1868, writing about heredity — with no knowledge of mitochondria, microbiomes, or genes as we understand them today — he mused:

> "*We cannot fathom the marvelous complexity of an organic being; but on the hypothesis here advanced this complexity is much increased. Each living creature must be looked as a microcosm — a little universe, formed of a host of self-propagating organisms, inconceivably minute and as numerous as the stars in heaven." (Darwin, The Variation of Animals and Plants under Domestication, 1868).*

Darwin couldn't have known about DNA or gut bacteria. But his instinct that a "living creature" is really a "little universe" built from smaller organisms, rather than one sealed-off individual, has turned out to be more literally true than he could have imagined.

Yong's argument, developed across the book, is that microbes don't just live alongside animals; they actively sculpt their host's organs, immune system, behavior, and even their ability to reproduce (Yong 2016). One of his most striking examples connect the holobiont directly back to the process of speciation. Biologists studying two populations of fruit fly that looked nearly identical found that the flies refused to mate with each other in the wild, seemingly repelled by subtle scent differences. It turned out those scent differences traced back to differences in each population's gut bacteria, not their own genes. When researchers treated both fly populations with antibiotics, wiping out the microbial differences, the two groups mated with each other without hesitation (Yong 2016). In other words, if left alone long enough, a difference that started in the microbiome could end up looking like the difference between one species and two, suggesting that natural selection may be acting on holobionts, not just on the genomes of their hosts.

An Anthropologist's Take: Multispecies Health

If the concept of the holobiont unsettles biology, it unsettles anthropology just as much, because it challenges a basic assumption most of us don't even realize we're making: that "the individual" is the natural unit to study when we ask what makes us human.

Biological anthropologist Agustín Fuentes has argued that human health, well-being, and even our ongoing evolution can't be fully understood by looking at a single human body in isolation. Extending the holobiont concept into questions of care and medicine, Fuentes argues that health is never simply an individual's private responsibility. Instead, it's the outcome of constant, ongoing relationships between human bodies, the microbes they carry, and the food systems, environments, and other species they're entangled with (Fuentes 2015; Tippett 2020).

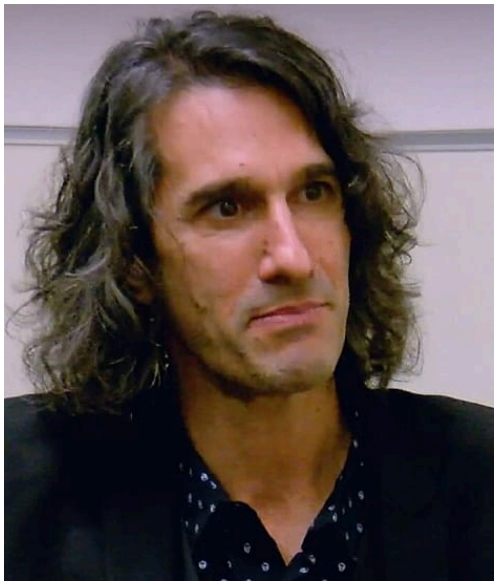


Figure 3.6.2: Anthropologist Agustín Fuentes. Image credit: Simulation, CC BY 3.0 via Wikimedia Commons.

This has practical consequences you may have already run into. It's part of why babies born by cesarean section, who miss out on the dose of microbes they'd otherwise pick up passing through the birth canal, tend to have a measurably different gut microbiome in early life than babies born vaginally. Researchers are still working to understand the long-term effects of this. It's also a part of why over-sanitizing our environments, or overusing antibiotics, doesn't just risk breeding resistant bacteria, it may also be quietly reshaping the internal ecosystems that keep us healthy in the first place, in ways we're only beginning to map and understand. Fuentes's work connects to his broader research on human niche construction: the idea that humans have never evolved alone. We've always been shaped by, and simultaneously shaping, the other organisms and environments we live among.

All Biology is Ecology

As science journalist Zoë Schlanger argues in her 2024 book, *The Light Eaters: How the Unseen World of Plant Intelligence Offers a New Understanding of Life on Earth,* no organism, humans included, is truly a separate, standalone entity—biology, at its core, is ecology. From a single microbe up to an entire rainforest, every level of life behaves less like an isolated unit and more like a system nested inside other systems. We carry the imprint of our surroundings, and even of our parents' surroundings, already built into us, bound up in a web of interconnection so complete that we ourselves are the proof of it. (Schlanger 2024:228-230; Hill 2026).

Reducing Diversity in Our Microbiome

This issue raises an important but uncomfortable question: if the microbiome is this central to who we are, what happens when it changes? A growing body of research suggests that modern, industrialized lifestyles have measurably narrowed the diversity of the human gut microbiome compared to people who still live a more traditional lifestyle today, one that more closely resembles our ancestors' than our own lifestyle does. Researchers at Stanford compared the gut microbiomes of the Hadza, a hunter-gatherer population in Tanzania, to people in Nepal and California. The average Hadza gut carried around 730 species of microbe; the average Californian gut carried just 277, with Nepali microbiomes falling in between the two (Conroy 2023; Carter et al. 2023; Smits et al. 2017). Similar patterns show up wherever researchers have looked, including among the Yanomami of the Amazon, with more traditional, high-fiber diets consistently associated with a wider range of gut bacteria than the low-fiber, heavily processed diets common in industrialized countries.

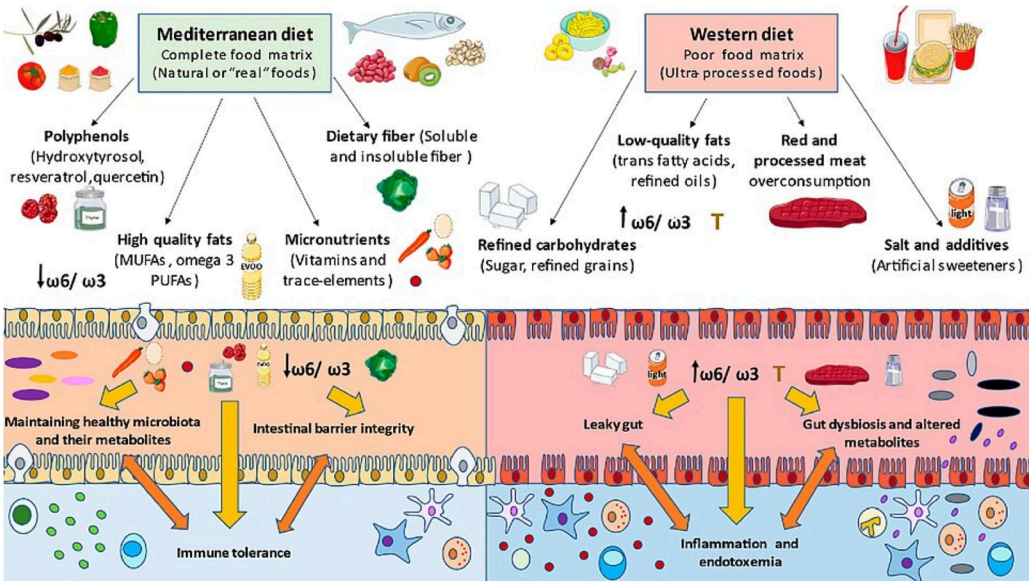


Figure 3.6.3: The interplay between diet, the microbiome, and immunity. Image credit: See attributions at the end of this chapter. Licensed under a CC BY-SA 4.0 via Wikimedia Commons.

But it isn't only diet. Researchers point to a whole cluster of modern lifestyle factors that appear to reduce microbiome diversity: ultra-processed food, frequent antibiotic use, birth by cesarean section rather than vaginal delivery, aggressive sanitation, and simply less everyday contact with soil, animals, and other people's microbes. When scientists have tracked people who move from a non-industrialized country to the United States, their gut microbiomes measurably shift toward the lower-diversity, more industrialized pattern within a relatively short time. This is a very strong hint that lifestyle, not ancestry, is tipping the scale.

Which brings the holobiont concept back around to Fuentes's point. If part of "you" is your microbiome, and human microbiomes are losing diversity across generations because of diet and modern lifestyle, then a real piece of human evolution is happening right now, not in human DNA, but in gut bacteria. It's a striking illustration of exactly what Fuentes argues: health, and evolution, were never just about a single, isolated human body.

So, Are We Still Evolving?

Which brings us back to the question this section opened with. Genetic evolution in the strict Darwinian sense — random mutation, differential survival, gradual shifts in gene frequency across generations — is almost certainly still happening in human populations, it's just too slow to notice within a single lifetime. But taking the holobiont seriously means there's a faster, messier, and more immediate layer of change happening alongside it. Your gut microbiome can shift noticeably within days, depending on what you eat or whether you've traveled somewhere new. It's partly inherited from your mother, partly assembled from your environment, and constantly open to being reshaped by antibiotics, diet, stress, and where you live.

A great deal of "you," in other words, is still very much a work in progress. As we'll explore in the next chapter, that work isn't only written into the genome you were born with.

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3.7: An Evolutionary Perspective

> ***"A species and a culture that treat the natural world with respect and reciprocity will surely pass on genes to ensuing generations with a higher frequency than the people who destroy it. The stories we choose to shape our behaviors have adaptive consequences."*** ~ Robin Wall Kimmerer, author of *Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge, and the Teachings of Plants.*

The Synthesizer and Systems Thinker

It's worth returning, one last time, to Darwin himself, not for more biological detail, but to emphasize more directly what made him so effective. As this chapter has shown again and again, Darwin didn't' invent evolution, and he wasn't even the most original thinker of his era. What set him apart was his gift for synthesis: the patience to gather evidence from geology, economics, embryology, pigeon breeding, and twenty years of his own household experiments, and weave them into a single coherent explanation. In today's language, we'd call this systems thinking — the ability to see not just isolated facts, but the relationships, feedback loops, and patterns connecting them. Darwin did more than collect puzzle pieces; he was one of history's great pattern-recognizers. He had the ability to hold a hundred small observations in mind at once and notice the shape they made together (Harel 2022; Sumner 2010).

That systems view extended to how Darwin saw life itself. He never placed humans at the top of a ladder, above or apart from the rest of nature. To Darwin, humans were simply one more species, shaped by the same processes as everything else alive. He marveled at the ingenuity of other organisms and speculated that even plants might have something like intelligence — an idea serious botanists are now revisiting, with research showing that plants can recognize their own relatives, release chemical alarm signals when threatened, and engage in forms of mutual aid with their neighbors (Kimmerer 2013; Schlanger 2024). Darwin was, in a real sense, always looking for the "oneness" underneath the diversity: the web of relationships — what he memorably called a "tangled bank" — binding every living thing to every other (Harel 2022; Keltner 2023).

The Tangled Bank: Awe, and Why It Mattered

What fueled that way of seeing the world? Psychologist Dacher Keltner, in his 2023 book, *Awe: The New Science of Everyday Wonder,* argues that Darwin's systems-level insight was powered by something very specific and profound: awe. Keltner's research treats awe not as a vague, dreamy feeling but a definable emotional response to encountering something so vast or intricate that it doesn't fit our existing mental categories. He points to Darwin as a prime historical example. Sitting beside a tangled riverbank thick with birds, insects, and earthworms quietly turning over the soil, Darwin saw the laws of growth, reproduction, inheritance, variation, and extinction all operating together, and it moved him.



Figure 3.7.1: A river bank filled with birds, insects, and earthworms in the soil, each playing a vital role in the tangled bank or web of life. Image produced by Google Gemini.

Keltner's decades-long research suggests this is exactly what awe does to the mind. It lessens our tendency toward self-focused thinking and opens us up to seeing bigger patterns, unfamiliar ideas, and our own place within something larger than ourselves. In Keltner's own words, "awe enables us to see the systems underlying the wonders of life" (Keltner 2023:245-246). He's careful to note that this isn't a new discovery so much as a rediscovery since systems thinking of this kind has been part of Indigenous knowledge traditions for thousands of years, long before Western science caught up to it. This is a fitting reminder that evolutionary thinking itself was never the sole domain of any one culture.

In Conclusion

As this chapter has tried to demonstrate, the logic that Darwin worked out — variation, selection, systems of interdependent parts — keeps showing up anywhere something changes under pressure: in overfished oceans, in antibiotic-resistant infections and the cancer treatments now borrowing that same insight, in NASA's computer-bred antennas, in the shrinking diversity of the human gut microbiome, and in the fate of consumer products in the marketplace. Misunderstanding this logic carries real costs and consequences for public health, the economy, and the environment whether or not we notice it happening. Understanding it, on the other hand, gives you a powerful and practical lens for your own daily choices.

Darwin was not only in awe of the beauty and complexity of the natural world; he was also comfortable sitting with uncertainty, without needing all the answers settled. This is what Darwin, and the evolutionary worldview he helped shape, invite us to do: to look closely at the biological, ecological, and social systems of which we are all a part. In Darwin's own words, closing *On the Origin of Species:*

> *"There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved."* (Darwin, On the Origin of Species, 1859).



Figure 3.7.2: Sun set in the Grand Canyon—one of the Seven Natural Wonders of the World. Image by Guy Pendlebury from Pixabay.

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3.8: Misconceptions About Natural Selection

> ***"Organisms don't evolve first one trait and then another, hauling themselves up the ladder of creation at each step, but in an integrated way, as you'd expect for creatures living on the tangled bank of Darwin's imagination."***
> ~ Henry Gee, author of *The Accidental Species: Misunderstandings of Human Evolution*

Because natural selection can produce amazing adaptations, it's tempting to think of it as an all-powerful force, urging organisms on, constantly pushing them in the direction of progress—but this is not what natural selection is like at all.

First, natural selection is not all-powerful; it does not produce perfection. It's all about getting genes into the next generation, and if your genes are "good enough" to do that, you don't have to be perfect. This should be clear just by looking around us: human populations carry genes that cause disease, plants may not have the genes to survive a drought, a predator may not be quite fast enough to catch her prey every time she is hungry. No population or organism is perfectly adapted.

Second, it's more accurate to think of natural selection as a process rather than as a guiding hand. Natural selection is the simple result of variation, differential reproduction, and heredity—it has no goals; it's not striving to produce "progress" or a balanced ecosystem.

Here are some common misconceptions along with some clarifications about how natural selection actually works.

MISCONCEPTION: Natural selection involves organisms trying to adapt.

CORRECTION: Natural selection leads to the adaptation of species over time, but the process does not involve effort, trying, or wanting. Natural selection naturally results from genetic variation in a population and the fact that some of those variants may be able to leave more offspring in the next generation than other variants. That genetic variation is generated by random mutation—a process that is unaffected by what organisms in the population want or what they are "trying" to do. Either an individual has genes that are good enough to survive and reproduce, or it does not; it can't get the right genes by "trying." For example, bacteria do not evolve resistance to our antibiotics because they "try" so hard. Instead, resistance evolves because random mutation happens to generate some individuals that are better able to survive the antibiotic, and these individuals can reproduce more than others, leaving behind more resistant bacteria.

MISCONCEPTION: Natural selection is about survival of the very fittest individuals in a population.

CORRECTION: Though "survival of the fittest" is the catchphrase of natural selection, "survival of the fit enough" is more accurate. In most populations, organisms with many different genetic variations survive, reproduce, and leave offspring carrying their genes in the next generation. It is not simply the one or two "best" individuals in the population that pass their genes on to the next generation. This is apparent in the populations around us: for example, a plant may not have the genes to flourish in a drought, or a predator may not be quite fast enough to catch her prey every time she is hungry. These individuals may not be the "fittest" in the population, but they are "fit enough" to reproduce and pass their genes on to the next generation.

MISCONCEPTION: The fittest organisms in a population are those that are strongest, healthiest, fastest, and/or largest.

CORRECTION: In evolutionary terms, *fitness* has a very different meaning than the everyday meaning of the word. An organism's evolutionary fitness does not indicate its health, but rather its ability to get its genes into the next generation. The more fertile offspring an organism leaves in the next generation, the fitter it is. This doesn't always correlate with strength, speed, or size. For example, a puny male bird with bright tail feathers might leave behind more offspring than a stronger, duller male, and a spindly plant with big seed pods may leave behind more offspring than a larger specimen — meaning that the puny bird and the spindly plant have higher evolutionary fitness than their stronger, larger counterparts.

MISCONCEPTION: Natural selection gives organisms what they need.

CORRECTION: Natural selection has no intentions or senses; it cannot sense what a species or an individual "needs." Natural selection acts on the genetic variation in a population, and this genetic variation is generated by random mutation—a process that is unaffected by what organisms in the population need. If a population happens to have genetic variation that allows some

individuals to survive a challenge better than others or reproduce more than others, then those individuals will have more offspring in the next generation, and the population will evolve. If that genetic variation is not in the population, the population may survive anyway (but not evolve via natural selection) or it may die out. But it will not be granted what it "needs" by natural selection.

MISCONCEPTION: Natural selection produces organisms perfectly suited to their environments.

CORRECTION: Natural selection is not all-powerful. There are many reasons that natural selection cannot produce "perfectly-engineered" traits. For example, living things are made up of traits resulting from a complicated set of trade-offs—changing one feature for the better may mean changing another for the worse (e.g., a bird with the "perfect" tail plumage to attract mates may be particularly vulnerable to predators because of its long tail). And of course, because organisms have arisen through complex evolutionary histories (not a design process), their future evolution is often constrained by traits they have already evolved. For example, even if it were advantageous for an insect to grow in some way other than molting, this switch simply could not happen because molting is embedded in the genetic makeup of insects at many levels.

MISCONCEPTION: Humans can't negatively impact ecosystems, because species will just evolve what they need to survive.

CORRECTION: As described in the misconception above, natural selection does not automatically provide organisms with the traits they "need" to survive. Of course, *some* species may possess traits that allow them to thrive under conditions of environmental change caused by humans and so may be selected for, but others may not and so may go extinct. If a population or species doesn't happen to have the right kinds of genetic variation, it will not evolve in response to the environmental changes wrought by humans, whether those changes are caused by pollutants, climate change, habitat encroachment, or other factors. For example, as climate change causes the Arctic sea ice to thin and break up earlier and earlier, polar bears are finding it more difficult to obtain food. If polar bear populations don't have the genetic variation that would allow some individuals to take advantage of hunting opportunities that are not dependent on sea ice, they could go extinct in the wild.

MISCONCEPTION: Natural selection acts for the good of the species.

CORRECTION: When we hear about altruism in nature (e.g., dolphins spending energy to support a sick individual, or a meerkat calling to warn others of an approaching predator, even though this puts the alarm sounder at extra risk), it's tempting to think that those behaviors arose through natural selection that favors the survival of the species — that natural selection promotes behaviors that are good for the species as a whole, even if they are risky or detrimental for individuals in the population. However, this impression is incorrect. Natural selection has no foresight or intentions. In general, natural selection simply selects among individuals in a population, favoring traits that enable individuals to survive and reproduce, yielding more copies of those individuals' genes in the next generation. Theoretically, in fact, a trait that is advantageous to the individual (e.g., being an efficient predator) could become more and more frequent and wind up driving the whole population to extinction (e.g., if the efficient predation actually wiped out the entire prey population, leaving the predators without a food source).

So what's the evolutionary explanation for altruism if it's not for the good of the species? There are many ways that such behaviors can evolve. For example, if altruistic acts are "repaid" at other times, this sort of behavior may be favored by natural selection. Similarly, if altruistic behavior increases the survival and reproduction of an individual's kin (who are also likely to carry altruistic genes), this behavior can spread through a population via natural selection.

Advanced students of evolutionary biology may be interested to know that selection can act at different levels and that, in some circumstances, species-level or group-level selection may occur. However, it's important to remember that, even in this case, selection has no foresight and is not "aiming" at any outcome; it is simply favoring the reproducing units that are best at leaving copies of themselves in the next generation.

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3.9: Key Terms

Adaptive radiation – an evolutionary process where a single ancestral species rapidly diversifies into multiple new species. This occurs when organisms encounter new environmental niches, such as after colonizing an isolated island chain or surviving a mass extinction, allowing them to evolve specialized traits to exploit different resources**.**

Artificial selection – The identification by humans of desirable traits in plants and animals, and the subsequent steps taken to enhance and perpetuate those traits in future generations.

Binomial nomenclature – A system of classification in which a species of animal or plant receives a name consisting of two terms: the first identifies the genus to which it belongs, and the second identifies the species.

Carrying capacity – The number of living organisms, including animals, crops, and humans, that a geographic area can support without environmental degradation**.**

Catastrophism – The theory that the Earth's geology has largely been shaped by sudden, short-lived, violent events, possibly worldwide in scope. Compare to uniformitarianism.

Convergent evolution – the independent evolution of similar features in unrelated or distantly related species.

Differential reproductive success – the difference in the number of surviving offspring produced by individuals within a population. Those individuals with traits best suited to their environment are more likely to survive and pass those traits (and the genes that produce them) to the next generation

Fitness – an organism's ability to survive and reproduce in a specific environment, thereby passing its genes on to the next generation. It is not a measure of physical strength or speed, but rather a gauge of reproductive success and genetic contribution.

Heredity – the process by which traits and characteristics are transmitted from parents to their offspring.

Hierarchy – an organizational structure that ranks items, people, or concepts based on relative importance, authority, or status.

Holobiont – an ecological and evolutionary unit composed of a host organism (such as an animal or plant) and all its associated microorganisms, like bacteria, viruses, and fungi.

Inheritance of acquired characteristics – theory about evolutionary change proposed by French naturalist, Jean Baptiste-Lamarck, and later disproven, that the physical traits an organism develops during its lifetime to adapt to its environment can be passed on to its offspring.

Microbiome – a dynamic, highly complex community of microorganisms—including bacteria, viruses, fungi, and parasites—that live in a particular environment.

Scala Naturae – The *Scala Naturae* (Latin for "ladder of nature"), also known as the Great Chain of Being, is an ancient philosophical and religious concept. It arranges all matter, life, and celestial beings into a single, hierarchical, and continuous linear ladder based on complexity.

Social Darwinism – a late 19th-century pseudoscientific theory that applies the biological concepts of natural selection and "survival of the fittest" to human societies.

Uniformitarianism – The theory that changes in the earth's crust during geologic history have resulted from the action of continuous and uniform processes—such as wind, precipitation, evaporation, condensation, erosion, and volcanic action—that continue to act in the present.

Variation – the differences between individuals within a species.

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3.10: References and Attributions

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Figure

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4: EVOLUTIONARY GENETICS

4.1: The Blueprint of Life- DNA

4.2: Making Proteins- How Genes Work

4.3: Passing Traits Down- Mendelian Inheritance

4.4: When DNA Changes- Mutations

4.5: Genetic Variation and Sexual Reproduction

4.6: Beyond the Sequence- The Human Genome and Epigenetics

4.7: Genetic Testing and Genetic Engineering

4.8: Key Terms

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Learning Objectives

- Explain the purpose of DNA replication.
- Identify the key differences between mitosis and meiosis.
- Outline the process of protein synthesis.
- Describe the principles of Mendelian inheritance.
- Identify complexities surrounding patterns of genetic inheritance, polygenic traits, and the influence of the epigenome.
- Consider challenges to and bioethical concerns of genetic testing and genetic engineering.



Figure 4.1: DNA molecule DNA is an organic compound in which the molecules hold the genetic instructions that organize the development and functioning of all living things, as well as some viruses. These compounds are responsible for transmitting the unique and specific characteristics of each living being. Image by Kadumago, CC BY 4.0 via Wikimedia Commons.

Chapter Overview: Genes, Heredity, and Evolutionary Genetics

Everything that makes you biologically unique—your blood type, your hair color, your risk for certain diseases, even some of your personality tendencies—has roots in your DNA. In this chapter, we explore how genetic information is stored, expressed, passed from parents to offspring, and changed over time, and why these processes matter for understanding human evolution

and biological diversity.

Two related fields study these questions from different angles**. Molecular geneticists** investigate the biological mechanisms that create variation between individuals, including DNA mutations, cell division, and gene regulation. **Molecular anthropologists** apply this genetic knowledge to anthropological questions—for example, by studying **ancient DNA (aDNA**), genetic material extracted from human, animal, or plant remains. Because DNA degrades over time, researchers use specialized techniques to piece together short, damaged fragments into more complete genetic information. This approach has given us fascinating new insights in our own species' history. Ancient DNA recovered from fossils has revealed that ancient humans interbred with both Neanderthals and Denisovans, groups of archaic humans who lived alongside our ancestors, tens of thousands of years ago. As a result, many people today still carry small portions of Neanderthal or Denisovan DNA in their **genomes**—a story we'll return to in Chapter 13.

Together, these approaches reveal that the traits that make us unique, both as individuals and as a species, are written in our DNA. Understanding the structure, function, and regulation of genes is therefore essential to understanding human evolution and the spectacular biological diversity we see today.

How to Use This Chapter

If genetics feels intimidating, you're not alone. It's a field with its own specialized and rather technical vocabulary, and it's easy to feel like you need to memorize every term and mechanism just to keep up. You don't.

This chapter doesn't aim to cover molecular genetics with the depth of a cell biology textbook. Instead, our goal is to build a working foundation in genetics: the core concepts you'll need to understand how traits vary, how they're inherited, and how populations change over time through evolutionary processes.

As you read, focus on the big ideas—what genes are, how traits are passed down, what mutations are and why they matter, and how genetic variation connects to evolution. If a term or process feels overly technical, ask yourself: *how does this connect to variation, inheritance, or evolution?* That's the lens this chapter, and this course, cares about most.

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4.1: The Blueprint of Life- DNA

Imagine you're building a house. Before anything gets constructed, you need a detailed set of blueprints. In the same way, every living thing carries a molecular blueprint inside nearly every cell. That blueprint is DNA.

What is DNA?

DNA (*deoxyribonucleic acid*) is a long molecule found in the nucleus of your cells. It carries the instructions your body needs to build and run itself, from the enzymes in your stomach to the color of your eyes. DNA is shaped like a **double helix,** or a twisted ladder**.** The sides of the ladder are made of sugar and phosphate molecules and the rungs are made of nucleotide base pairs.

There are four chemical bases in DNA—adenine (A), thymine (T), cytosine (C), and guanine (G)—sometimes called the "letters" of the genetic code. They always pair up in the same way. A pairs with T, and C pairs with G. This complementary base-pairing is what allows DNA to be copied accurately when cells divide.

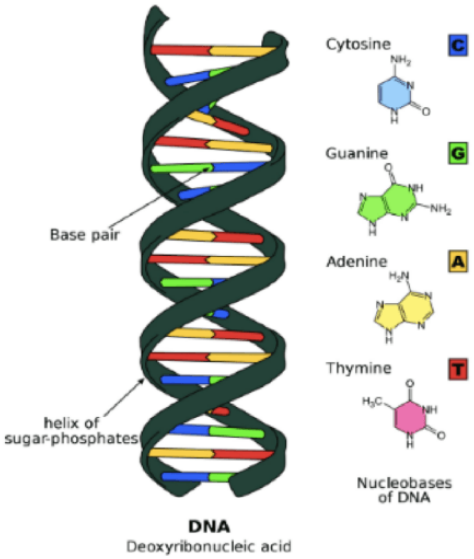


Figure 4.1.1: Structural components that form double-stranded nucleic acid (DNA). Credit: Difference DNA RNA-EN by Sponk (translation by Sponk, cropped by Katie Nelson) is under a CC BY-NC-SA 4.0 License.

From DNA to Chromosomes

If you stretched all the DNA in a single human cell, it would measure roughly 6.5 feet, yet it fits inside a **nucleus** smaller than a grain of sand. How? DNA is tightly coiled around proteins called **histones**, forming a structure called **chromatin** which resembles "beads on a string." Chromatin then coils further into chromosomes.

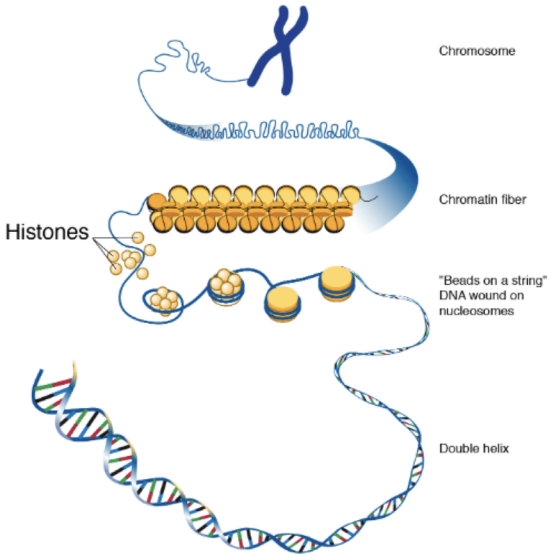


Figure 4.1.2: The hierarchical organization of chromosomes. Credit: Histone (2019) by NIH National Human Genome Research Institute is in the public domain.

Human body cells normally contain 46 chromosomes arranged in 23 pairs. One chromosome in each pair came from your biological mother and the other from your biological father. The matching chromosomes in each pair are called **homologous chromosomes** and carry genes for the same traits, though not necessarily the same versions of those genes.

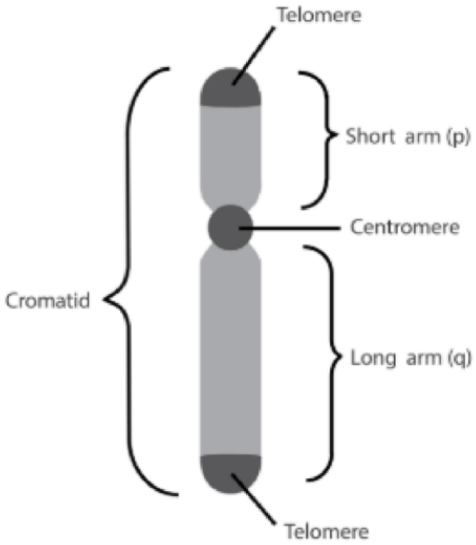


Figure 4.1.3: The regions of a chromosome. Credit: Chromosome (Figure 3.16) original to Explorations: An Open Invitation to Biological Anthropology by Katie Nelson is under a CC BY-NC 4.0 License.

Two of those 46 chromosomes are the **sex chromosomes**, labeled X and Y. People who are biologically female typically have two X chromosomes (XX), while those who are biologically male typically have one X and one Y (XY). The remaining 22 pairs are called **autosomes** and carry most of our other traits.

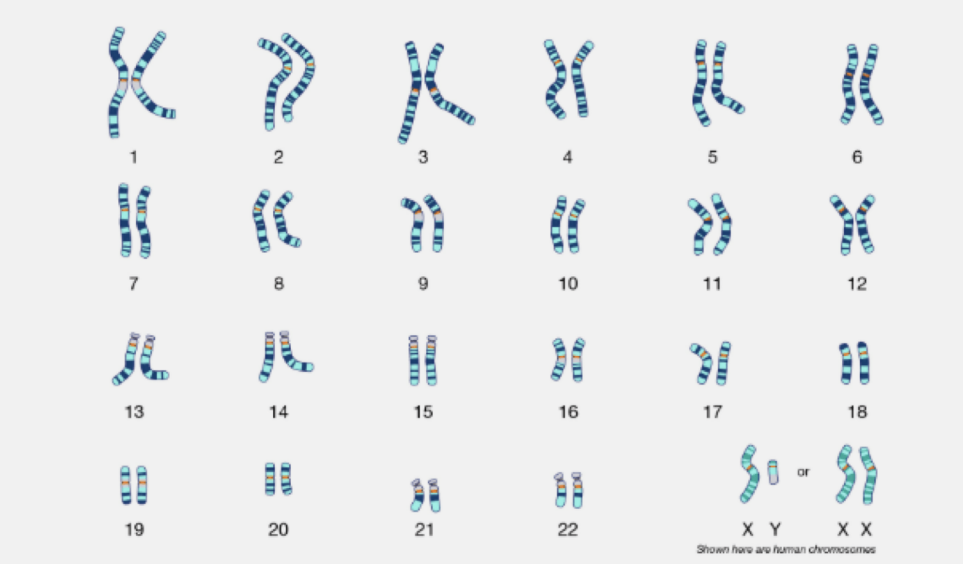


Figure 4.1.4: The 23 human chromosome pairs. Credit: Genome (2019) by NIH National Human Genome Research Institute is in the public domain.

Genes and Alleles

A **gene** is a specific segment of DNA that contains instructions for building a protein. Humans have roughly 20,000 – 25,000 protein-coding genes which is far fewer than many scientists originally expected. Genes take up only about 2% of our total DNA; the rest includes regulatory regions, repetitive sequences, and areas that are still being studied (Mortola and Long, 2021).

Most genes come in slightly different versions called **alleles**. Think of alleles like editions of the same book. The story is the same, but some details differ. For example, the gene for ABO blood type groups comes in several alleles (A, B, and O). Which two alleles you inherit from your parents determines your blood type.

This explains why siblings look similar, but not identical even though they have the same parents. Each parent passes down a different combination of alleles every time. With over 20,000 genes and multiple alleles for each, the number of possible genetic combinations is astronomically large. This is partly why no two people (except identical twins) have exactly the same DNA.

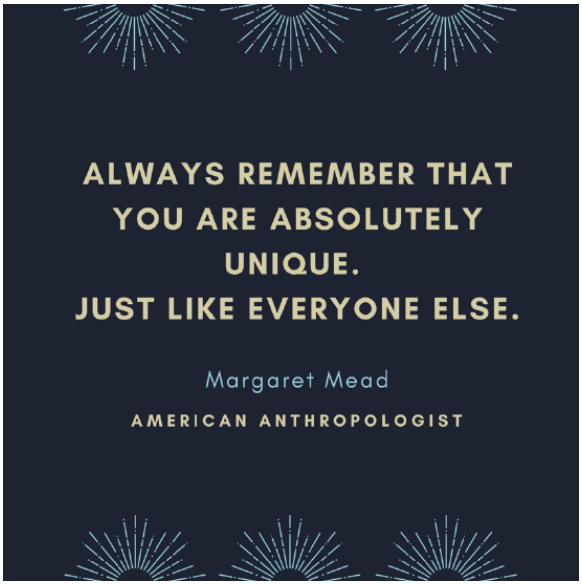


Figure 4.1.5: Margaret Meade quote. Canva design by Rachel Mitchell.

DNA Replication

For life to continue, cells must be able to divide, whether to help an organism grow, repair damaged tissue, or produce new cells throughout its life. Before a cell divides, it must first make an exact copy of its DNA, a process called DNA replication.

Think of DNA replication like making a copy of a zipper. The two strands of the DNA double helix are “unzipped” by an enzyme called **helicase,** which separates them by breaking the weak bonds between base pairs. This exposes the two original strands, each of which now serves as a template for building a new, matching strand.

Because A always pairs with T, and C always pairs with G, each original strand acts as a guide. Wherever there’s an A on the original strand, the enzyme DNA **polymerase** adds a T to the new strand, and so on. The result is two complete DNA molecules, each made of one original (“parent”) strand and one newly built (“daughter”) strand. This is why the process is called **semi-conservative replication**: each new DNA molecule conserves, or keeps, half of the original.

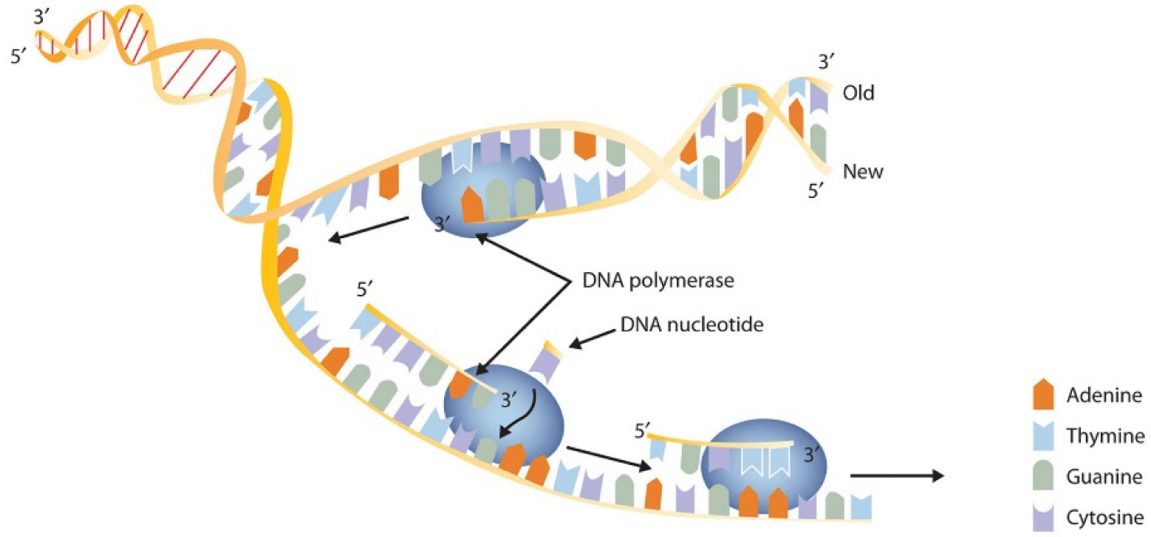


Figure 4.1.6: A Schematic Diagram of DNA Replication. DNA replication occurs by the sequential unzipping of segments of the double helix. Image source shared under " href="/%3Chttps://creativecommons.org/licenses/by-sa/4.0%3E">CC BY-SA 4.0 via Wikimedia Commons.

Once replication is complete, the cell has two full copies of its DNA—one for each of the two new cells that will form when it divides. This doubling of DNA is essential before a cell can divide, whether through **mitosis**, which produces identical cells for growth and repair, or **meiosis**, which produces sperm and egg cells. We’ll return to these two types of cell division, and why they matter for genetic variation, in section 4.5.

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4.2: Making Proteins- How Genes Work

Genes don't directly build bodies. Instead, they provide instructions for making proteins, and proteins do the actual work, from forming structures like hair and muscle, to acting as enzymes, hormones, and immune defenders.

The Central Dogma: DNA → RNA → Protein

If the chromosomes lie in the nucleus of the cell, how do the instructions in DNA get to the site of protein synthesis outside the nucleus? Another type of nucleic acid is responsible. This nucleic acid is **RNA** or ribonucleic acid. RNA is a small molecule that can squeeze through pores in the nuclear membrane. It carries the information from DNA in the nucleus to a ribosome in the cytoplasm of the cell and then helps assemble the protein.

In short:

DNA → RNA → Protein

Discovering this sequence of events was a major milestone in molecular biology. It is called the **central dogma of biology**. The two processes involved in the central dogma are **transcription** and **translation.**

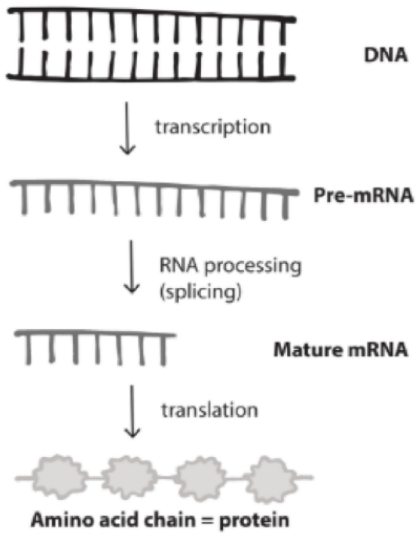


Figure 4.2.1: The major steps of protein synthesis. Credit: Protein synthesis original to Explorations: An Open Invitation to Biological Anthropology (2nd ed.) by Mary Nelson is under a CC BY-NC 4.0 License.

Transcription: Inside the nucleus, a section of DNA is "read" and used as a template to produce a molecule called messenger RNA (mRNA). Think of mRNA as a photocopy of the original blueprint. It can leave the nucleus and travel to where proteins are made.

Translation: The mRNA travels to a ribosome in the cytoplasm. There, the sequence of the mRNA is read in three-letter "words" called **codons**, each of which corresponds to a specific amino acid. **Amino acids** are strung together to form a protein.

> **The Genetic Code in Simple Terms**
>
> There are 64 possible three-letter codons, but only 20 amino acids. This means multiple codons can code for the same amino acid—a bit like how "sofa" and "couch" both refer to the same piece of furniture. Three codons act as "stop signs" that signal the end of a protein.

Polygenic Traits: Many Genes, One Trait

Some traits, like the pea plant flower color Mendel studied, are controlled by a single gene, making them **monogenic**. These produce limited variation and are called Mendelian traits. But most human traits are **polygenic,** meaning they're influenced by many genes working together.

Hair color is a great example. The gene MC1R influences whether you produce dark or reddish pigment, but at least a dozen other genes also contribute. Eye color, height, and skin tone all work the same way so these traits exist on a spectrum rather than falling into a few neat categories, precisely because so many genes are involved.



Figure 4.2.2: Human variation in eye color, height, hair color, and skin tone. Image produced by Google Gemini.

Complex diseases like Type 2 diabetes, heart disease, and schizophrenia are also polygenic. Your genes may increase or decrease your risk, but environment, diet, and lifestyle are part of the picture too. This is why you can't look at a single gene and say "this gene causes diabetes." The reality is always more complicated.

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4.3: Passing Traits Down- Mendelian Inheritance

Long before scientists knew what DNA was, an Austrian monk named Gregor Mendel figure out the basic rules of heredity by carefully breeding pea plants in his monastery garden in the 1860s. His work was ignored for decades, then recognized as foundational to all of genetics.

Dominant and Recessive Alleles

Mendel noticed that when he crossed purple-flowered plants with white-flowered plants, the first generation of offspring all had purple flowers. But when those offspring bred with each other, about one in four plants had white flower. The white trait hadn't disappeared—it had been hidden.

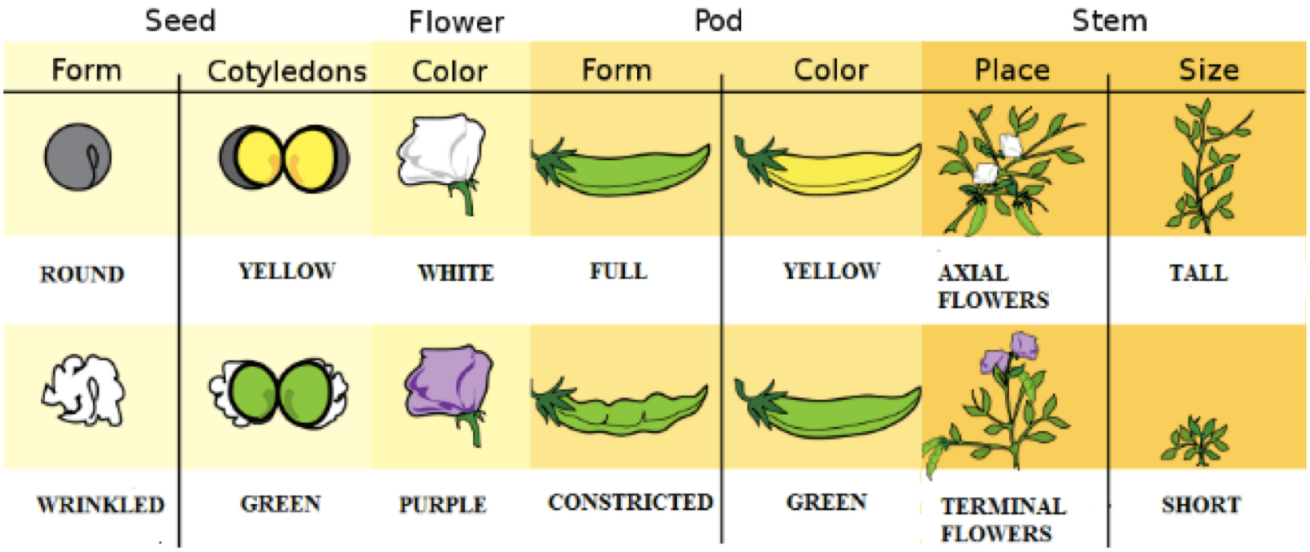


Figure 4.3.1: Various phenotypic characteristics of pea plants resulting from different genotypes. Credit: Mendels peas by Mariana Ruiz LadyofHats has been designated to the public domain (CC0 1.0).

He explained this with the concepts of dominant and recessive alleles (or, particles, as he called them since this was long before DNA and genes were discovered). A dominant allele is expressed whenever it's present. A recessive allele is only expressed when two copies are present (one from each parent).

Genotype vs. Phenotype: Your **genotype** is the actual allele combination you carry (e.g., Bb). Your **phenotype** is the physical, visible trait that results (e.g., purple flowers). Two organisms can have the same phenotype but different genotypes. For instance, a purple-flowered plant might be BB or Bb.

Homozygous vs. Heterozygous: If you have two identical alleles for a gene (like BB or bb), you're **homozygous** for that gene. If your two alleles differ (Bb), you're **heterozygous**.

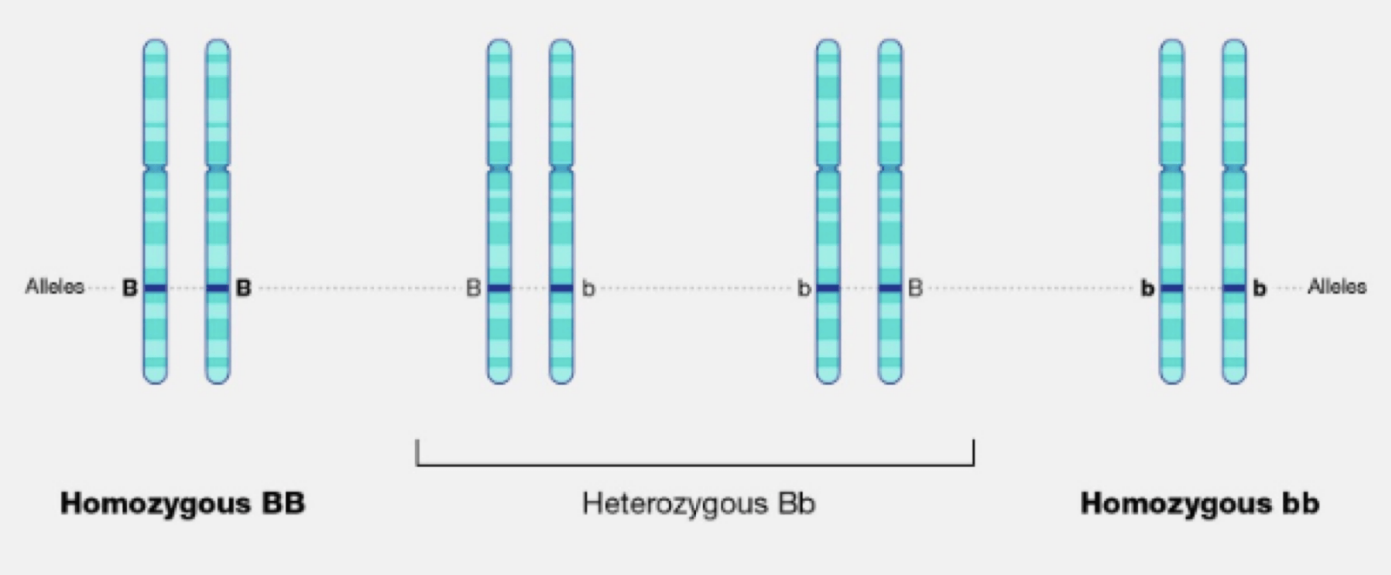


Figure 4.3.2: Homozygous refers to having the same alleles (e.g. two capital Bs or two lowercase bs). Heterozygous refers to having two different alleles (e.g. one capital B and one lowercase b). Credit: Homozygous by NIH National Human Genome Research Institute is in the public domain.

A Punnett square is a diagram that can help visualize Mendelian inheritance patterns. For instance, when parents of known genotypes mate, a Punnett square can help predict the ratio of Mendelian genotypes and phenotypes that their offspring would possess. When discussing genotype, biologists use upper and lower case letters to denote the different allele copies. Figure 3.26 is a Punnett square that includes two **heterozygous** parents for flower color (Bb). A heterozygous genotype means there are two different alleles for the same gene. Therefore, a pea plant that is heterozygous for flower color has one purple allele and one white allele. When an organism is **homozygous** for a specific trait, it means their genotype consists of two copies of the same allele. Using the Punnett square example, the two heterozygous pea plant parents can produce offspring with two different homozygous genotypes (BB or bb) or offspring that are heterozygous (Bb).

Mendel's Laws

The Law of Segregation was introduced by Mendel to explain why we can predict the ratio of genotypes and phenotypes in offspring.

Law of Segregation: The two alleles a parent carries for a gene are separated during formation of **gametes** (sperm and eggs), so each gamete receives only one allele. Offspring then receive one allele from each parent.

Independent Assortment: Alleles for different genes sort into gametes independently of each other (assuming the genes are on different chromosomes). This is one reason siblings can inherit such different combinations of traits from the same parents.

The ABO Blood Group System

In 1901, an Austrian scientist named Karl Landsteiner made a discovery that would go on to save countless lives. While experimenting with blood from different individuals, he noticed that mixing certain combinations caused blood to clump together, a reaction called **agglutination**. Other combinations mixed together with no reaction at all. Landsteiner had discovered that people have different blood types, and that those types are not always compatible with one another.

This discovery mattered immensely for blood transfusions. Before Landsteiner's work, transfusions were a gamble. If a patient received blood of an incompatible type, the agglutination reaction could cause clumps of blood cells to block blood vessels, often with fatal results. Once doctors understood blood typing, transfusions became dramatically safer. Landsteiner received the Nobel Prize in 1930 for this discovery.

So what causes one blood type to be incompatible with another? The answer lies on the surface of red blood cells, which are coated with molecules called **antigens**. Your blood plasma also contains **antibodies**, which are like trained defenders that

recognize and attack antigens they consider foreign. The agglutination Landsteiner observed happens when antibodies in one person's blood encounter and bind to antigens they recognize as "not mine" in another person's blood.

The ABO system is based on just two possible antigens, A and B, which gives us four possible blood types:

- **Type A** has A antigens on its red blood cells and produces anti-B antibodies
- **Type B** has B antigens on its red blood cells and produces anti-A antibodies
- **Type AB** has both A and B antigens, and produces neither anti-A nor anti-B antibodies
- **Type O** has neither A nor B antigens, and produces both anti-A and anti-B antigens

This is why blood type compatibility matters so much for transfusions. If a person with Type A blood (carrying anti-B antibodies) receives Type B blood, their anti-B antibodies will attack the donated cells, triggering the dangerous agglutination reaction Landsteiner first observed. Matching blood types correctly is what makes modern transfusions safe.

Figure 4.3.4 shows a table of the ABO allele system, which has a Mendelian pattern of inheritance but with a twist. There are three alleles for the ABO gene: A, B, and O. Both A and B are dominant over O, but co-dominant with each other. This makes the O allele recessive. Someone with one A allele and one B allele has blood type AB with both A and B antigens produced. Blood type O requires two copies of the recessive allele.

	A	**B**	**O**
A	AA	AB	AO
B	AB	BB	BO
O	AO	BO	OO

Figure 4.3.4:The different combinations of ABO blood alleles (A, B, and O) to form ABO blood genotypes. Credit: ABO Blood Genotypes (Figure 3.33) original to Explorations: An Open Invitation to Biological Anthropology by Katie Nelson is under a CC BY-NC 4.0 License.

Linked Genes and Sex-Linked Traits

Mendel's rules work perfectly when genes are on different chromosomes But genes located on the same chromosome tend to be inherited together—they are linked. For instance, genes for hair color and eye color are located near each other on the same chromosome, which is why certain combinations (like brown hair and brown eyes) tend to run together in families.

Genes on the X chromosome are called **X-linked** (or **sex-linked**). Since males have only one X chromosome, they express whatever allele is on that single X, even if it's recessive. This is why conditions like red-green colorblindness and Duchenne muscular dystrophy affect males much more than females. Females have a second X chromosome that can carry a functional allele, while males have no backup copy.

Reading a Pedigree

A **pedigree** is a family tree that shows which individuals in a family have a particular trait or disease. Circles represent females, squares represent males, and solid color shapes indicate affected individuals. By studying a pedigree, researchers can determine whether a condition is dominant or recessive, autosomal, or X-linked.

Dominant conditions (like Huntington's disease) appear in every generation. Affected individuals almost always have at least one affected parent. Figure 4.3.5 is a pedigree example of a family with Huntington's disease, which has a Mendelian pattern of inheritance. Biological family members are connected to a horizontal line with parents above and offspring below. Solid color shapes show the family members affected. In the case of Huntington's some individuals may not be diagnosed until later in

adulthood, so parents may unknowingly pass this dominantly inherited disease to their children.

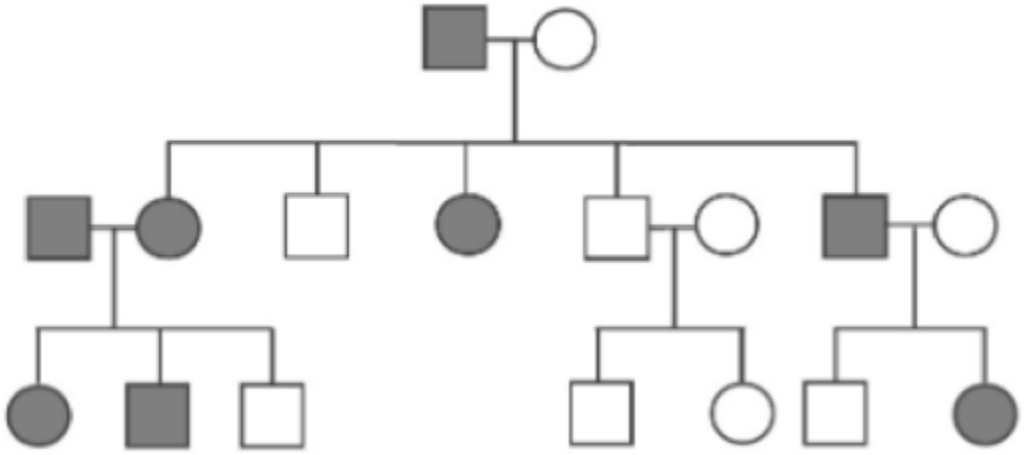


Figure 4.3.5: A pedigree depicting an example of dominant Mendelian inheritance like Huntington's. Offspring with the trait will have at least one parent with the same trait. Credit: Mendelian dominant pattern of inheritance (Figure 3.34) original to Explorations: An Open Invitation to Biological Anthropology by Beth Shook is under a CC BY-NC 4.0 License.

Recessive conditions (like cystic fibrosis) can skip generations. Two unaffected carrier parents (Aa x Aa) have a 25% chance of having an affected child (aa). Figure 4.3.6 is an example of a family that carries a recessive cystic fibrosis mutation.

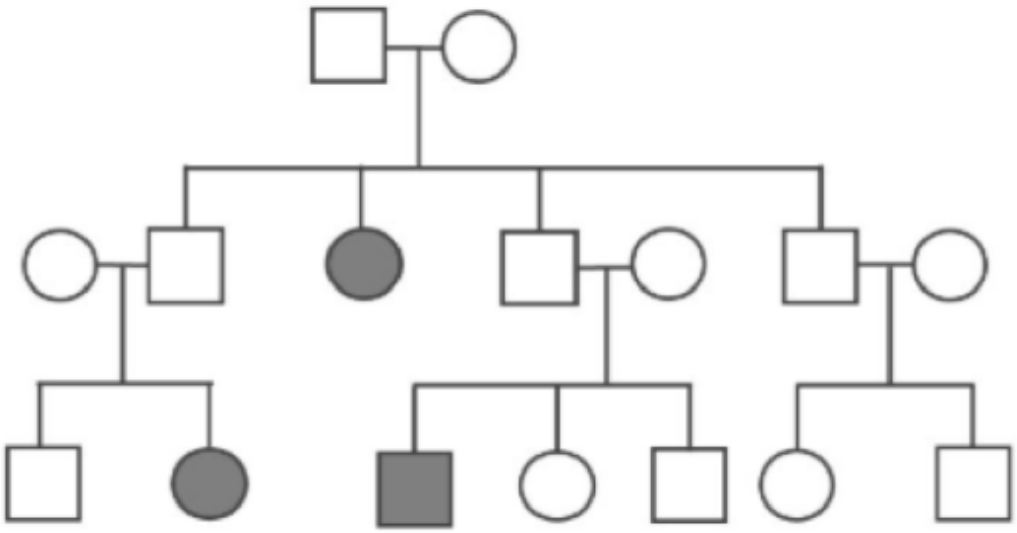


Figure 4.3.6: A pedigree depicting an example of recessive Mendelian inheritance like cystic fibrosis. Individuals may have a trait not observed in the previous generation. Credit: Mendelian recessive pattern of inheritance (Figure 3.35) original to Explorations: An Open Invitation to Biological Anthropology by Beth Shook is under a CC BY-NC 4.0 License.

X-linked conditions follow yet another pattern, reflecting the inheritance rules discussed above. Figure 4.3.7 depicts a family in which the mother is a carrier for the X-linked recessive disease Duchenne Muscular Dystrophy (DMD). Because she is a carrier, both her sons and daughters have a 50% change of inheriting the DMD allele, though only sons who inherit it will be affected since they have no second X chromosome to compensate.

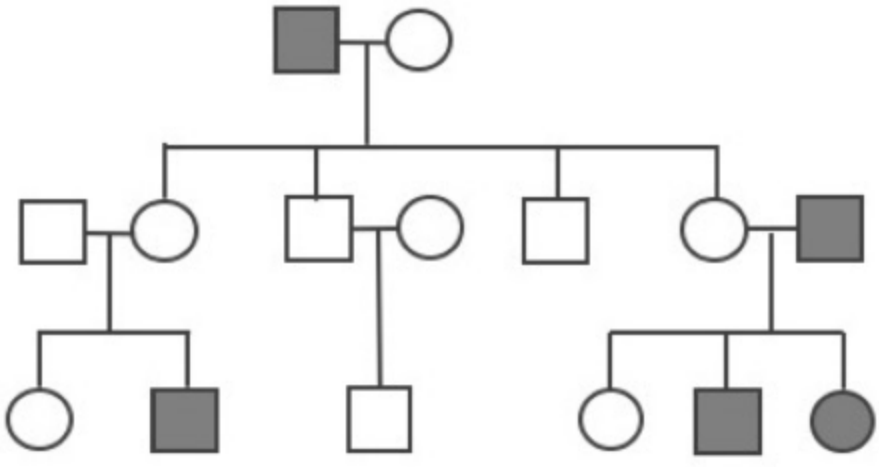


Figure 4.3.7: A pedigree depicting an example of X-linked Mendelian inheritance like Duchenne Muscular Dystrophy (DMD). Credit: X-linked recessive pattern of inheritance (Figure 3.36) original to Explorations: An Open Invitation to Biological Anthropology by Beth Shook is under a CC BY-NC 4.0 License.

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4.4: When DNA Changes- Mutations

For the most part, DNA replication is very accurate, but it isn't perfect. Sometimes the sequence of bases gets altered. These changes are called **mutations**, and they are actually one of the most important phenomena in all of biology, because without them, evolution couldn't happen.

What is a Mutation?

A mutation is any change in the nucleotide sequence of DNA. The word often conjures images of science fiction monsters or superheroes with incredible abilities. In reality, mutations are extremely common. Every one of us carries dozens or even hundreds of mutations, and the majority of them have not noticeable effect.

Mutations can occur spontaneously during DNA replication like a kind of copying error, or be triggered by environmental agents called **mutagens**—things like UV radiation from the sun, certain chemicals, or high-energy radiation.



Figure $4.4.1a-c$: Examples of mutagens. a) UV radiation. Photo by Ricky Bonilla on Unsplash; b) Cigarette smoke. Image by Challiyil Eswaramangalath Vipin from Chalakudy, India, CC BY-SA 2.0, via Wikimedia Commons; c) Radiation warning symbol. Original image by: Unknown author. Vector: Uwe W., Public domain, via Wikimedia Commons.

Types of Mutations

Point mutations involve a change in a single nucleotide. The effect depends on what the change does to the resulting protein:

- A **silent mutation** changes a codon but codes for the same amino acid with no change to the protein.
- A **missense mutation** changes the codon so a different amino acid is inserted which may make the protein work differently or not at all.
- A **nonsense mutation** creates a premature stop codon, shortening the protein.

Frameshift mutations happen when a nucleotide is inserted or deleted, shifting the entire reading frame. Because the cell reads codons in groups of three, even one extra or missing nucleotide scrambles every codon that follows. These mutations often have dramatic effects.

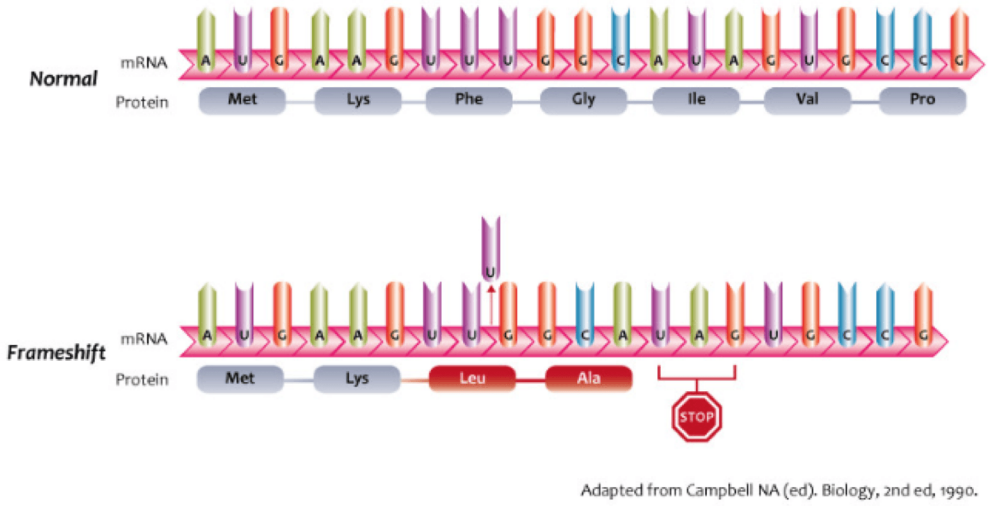


Figure 4.4.2: The image shows how the frame of the coding sequence of a gene changes when a nucleotide gets deleted due to mutation. Normal gene codes for a polypeptide met-lys-phe-gly-ile-val-pro. When a U from the third position of the third codon gets deleted, the polypeptide reduced to met-lys-leu-ala because the third and fourth codons code for different amino acids and the fifth codon converts to a stop codon. Image credit: Frameshift mutation by Genomics Education Programme, licensed CC BY 2.0 via Wikimedia Commons.

Chromosomal alterations affect entire chromosomes. Segments can be deleted, duplicated, inverted, or translocated to a different chromosome. Down syndrome (trisomy 21), for example, results from having three copies of chromosome 21 instead of two.



Figure 4.4.3: Amy Bockerstette, a competitive golfer and disabilities advocate, also has Down Syndrome. Credit: Amy Bockerstette Headshot by Bucksgrandson is under a CC BY-SA 4.0 License.

Mutations and Evolution

From an evolutionary perspective, mutations are essential—they are the raw material of evolution. Most are neutral or harmful in the short term, but occasionally a mutation produces a slight advantage in a particular environment and spreads through a population over generations. The immense diversity of life on Earth ultimately traces back to accumulated mutations over billions of years.

Germline vs. Somatic Mutations

Germline mutations occur in sperm or egg cells. Because gametes are passed on to offspring, germline mutations are heritable and can be transmitted to children and grandchildren.

Somatic mutations occur in other body cells. They affect only the individual and cannot be passed to offspring. However, somatic mutations can accumulate over a lifetime and are a major cause of cancer.

A Built-in Edit Button for Evolution

If DNA is a blueprint, RNA is the messenger that carries those instructions to the rest of the cell. Normally, that message is copied faithfully. But octopuses appear to break this rule.



Figure 4.4.4:Common octopus. Olga Ernst, CC BY-SA 4.0 via Wikimedia Commons.

Researchers have discovered that octopuses can edit their own RNA on the fly, effectively rewriting the message before it's used. This gives individual octopuses a way to adjust traits, like tolerance to cold water, without waiting for a DNA mutation to spread through the population over generations. Some evidence suggests this editing ability may be linked to octopus intelligence as well. Nautiluses, close relatives that lack this RNA-editing trick, are notably less clever.

But this flexibility comes at a cost. To protect their RNA-editing system, octopus DNA is unusually resistant to mutation—the raw material evolution normally relies on. So while an individual octopus can fine-tune itself in real time, the species as a whole barely changes from one generation to the next.

This is a vivid example of the trade-offs you've been learning about: mutation drives long-term evolutionary change, but it also introduces risk. Octopuses seem to have found a workaround by sacrificing some of that mutation rate in exchange for a built-in editing tool that lets individuals adapt within their own lifetime. It's a reminder that the central dogma isn't always a one-way street, and that evolution can solve the same problem—adapting to a changing environment—in more than way.

Source: Scharping, N. (2018, January 1). Octopuses Can Stray From Their DNA. *Discover*, *39*(1), 38–39.

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4.5: Genetic Variation and Sexual Reproduction

Recall from Section 4.1 that before any cell can divide, it must first replicate its DNA, doubling its genetic material. What happens next depends on the *type* of cell division that follows. One of the most powerful engines of variation in sexually reproducing species is the process of **meiosis**—the cell division that produces the reproductive cells, or **gametes**. Through several mechanisms, meiosis shuffles the genetic deck, ensuring that each gamete, and therefore each offspring, is genetically unique.

Mitosis vs. Meiosis: A Quick Comparison

Mitosis is cell division for growth and repair. It produces two genetically identical daughter cells with the full set of 46 chromosomes. Meiosis is cell division for reproduction. It produces four genetically unique gametes (sperm or eggs), each with only 23 chromosomes (half the normal number). When sperm and egg unite at fertilization, the full count of 46 is inherited by the **zygote**, the fertilized cell.

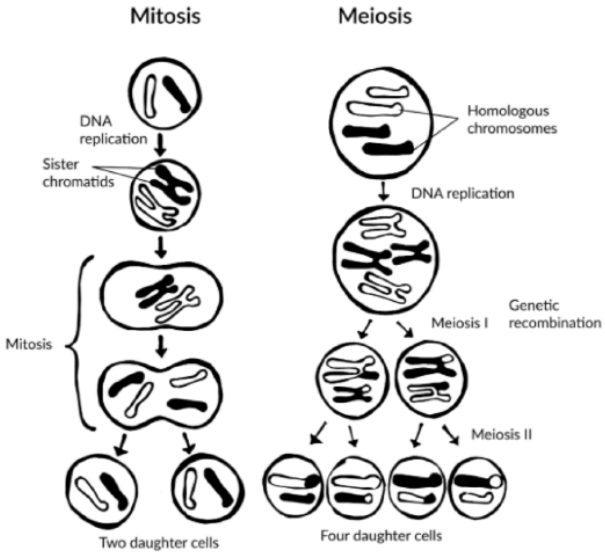


Figure 4.5.1: The steps of mitotic cell division and meiotic cell division. Credit: Mitosis and meiosis original to Explorations: An Open Invitation to Biological Anthropology (2nd ed.) by Katie Nelson is a collective work under a CC BY-NC 4.0 License. [Includes Mitosis (Figure 3.20) and Meiosis (Figure 3.21) by Mary Nelson; CC BY-NC 4.0 License.

Sources of Genetic Variation

Crossing over: During meiosis, homologous chromosomes line up side by side and swap segments of DNA. This recombination creates new combinations of alleles on each chromosome that never existed before.

Independent assortment: The 23 pairs of chromosomes are sorted into gametes entirely randomly. Because each pair segregates independently, there are over 8 million possible chromosome combinations in each gamete just from this mechanism alone.

Random fertilization: Which specific sperm fertilizes which specific egg is largely a matter of chance. Combining this with the

variation in gametes, any two human parents have the potential to produce over 64 trillion genetically distinct offspring!

Horizontal Gene Transfer: The Real Life "Superpower" of Bacteria and Plants

Throughout this chapter, you've learned that genes are normally passed down vertically from parent to offspring. But what if a plant could pick up genes from a completely unrelated species growing next to it with no breeding involved at all?

For decades, biologists assumed this kind of gene-swapping, known as **horizontal (or lateral) gene transfer**, was something only bacteria did. Single-celled organisms trade DNA all the time, but complex multicellular life—including plants, animals, and fungi—was thought to inherit genes only the traditional way, through reproduction.



Figure 4.5.2: Wheat plants. Image credit: Copyright © 2007 David Monniaux, CC BY-SA 3.0 via Wikimedia Commons.

That assumption is now being overturned. Researchers led by Luke Dunning at the University of Sheffield examined the genomes of 17 grass species, some of which had been evolving on separate paths for roughly 50 million years. The list included familiar food crops such as rice, wheat, and millet. What they found was that 13 of 17 species carried genes that appear to have jumped in from another species entirely, about 170 transferred genes in total. The closer the two grass species were related, the more likely this gene-swapping had occurred. Grasses that spread using rhizomes (underground stems that sprout new shoots and roots) were especially prone to it, hinting that physical contact between root systems may create opportunities for DNA to cross between species.

Why Should You Care?

Since many of the crops we eat have been genetically engineered to include traits like pest-resistant toxins or built-in sterility (so farmers must buy new seed each season), this raises concerns about engineered traits potentially spreading into wild or non-target crops in ways no one intended, and that could be difficult if not impossible to reverse.

More broadly, this discovery is a reminder that the "rules" of inheritance you're learning in this chapter aren't the whole story of how DNA moves through the living world. In other words, evolution doesn't just work by the textbook.

Source: Marshall, M. (2021, May 1). Plants routinely swap DNA. *New Scientist,* 250(3332), 11–11. https://doi.org/10.1016/S0262-4079(21)00718-1

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4.6: Beyond the Sequence- The Human Genome and Epigenetics

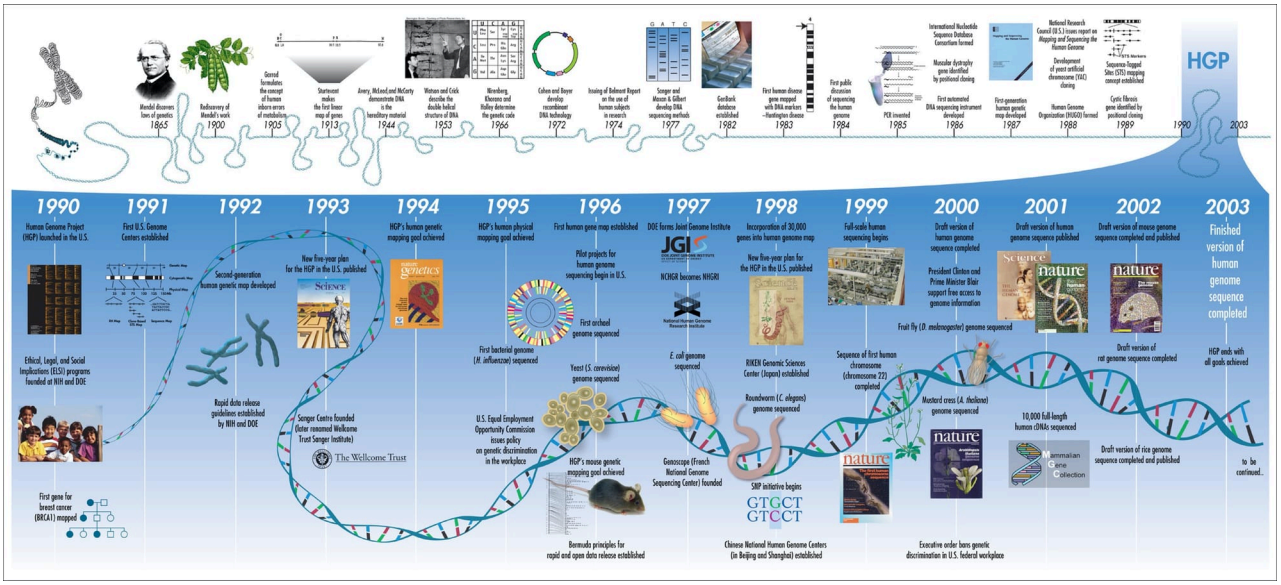


Figure 4.6.1: National Human Genome Research Institute (NHGRI) from Bethesda, MD, USA, CC BY 2.0, via Wikimedia Commons.

In 1990, scientists launched one of the most ambitious research endeavors in history: the Human Genome Project (HGP). The goal was to map and sequence the entire human genome, all three billion base pairs of DNA in a human cell. The project was completed in 2003, two years ahead of schedule, at a cost of about $3 billion.

Among some of the surprises were that the human genome contains only about 20,000 – 25,000 protein-coding genes (far fewer than expected), and protein-coding sequences make up only 2% of our total DNA. Much of the rest was initially dismissed as "junk DNA," but researchers are increasingly discovering important regulatory and structural functions in these regions (Mortola & Long, 2021).

Th Human Genome Project opened the door to major advances: Personalized medicine, which allows doctors to tailor drug treatments to individual genetic profiles; a deeper understanding of inherited diseases; and new tools for studying human evolutionary history.

It's not, however, without its flaws and limitations. Ninety-five percent of the genomes analyzed for the project came from people of European ancestry, and the same is true of roughly 95% of clinical trial participants. This matters because people from different genetic backgrounds can metabolize and respond to drugs differently. As geneticist Dr. Keolu Fox has asked: Who is the Human

Genome Project really for?

Geneticist Profile: Dr. Keolu Fox and the Fight for a More Representative Genome



Figure 4.6.2: Geneticist Dr. Keolu Fox. Image credit: CoolandDeadly, CC BY 4.0 via Wikimedia Commons.

Dr. Keolu Fox has spent his career working to answer that question. A Kānaka Maoli (Native Hawaiian) geneticist, Fox earned his Ph.D. in genome sciences at the University of Washington before joining the faculty at UC San Diego, where he is now a professor in the Department of Anthropology and co-director of the Indigenous Futures Lab.

Fox's research found that less than 5% of the genetic data used in major genome studies came from non-European populations, and less than 1% came from Indigenous communities. This gap matters because many genetic variants that affect health—from disease risk to drug metabolism—occur at very different frequencies across populations. If the reference genome is built almost entirely from one group, researchers risk missing, or misunderstanding, variation that matters for most of humanity.

For example, Fox has studied gene variants common in Pacific Islander populations that may influence how the body stores fat and processes energy. These variants may reflect adaptations to historical diets and voyaging lifestyles, but today they intersect with rising rates of diabetes and metabolic disease in these communities.

Dr. Fox has been committed to helping Indigenous communities build their own genomic research capacity rather than simply serving as subjects of outside studies. His work on Indigenous data sovereignty raises questions that are easy to overlook in genetics lessons: who owns genetic data, who gets to interpret it, and who benefits when it's used?

Fox's work is a reminder that the genome isn't a single, fixed "blueprint" that applies equally to everyone. It's a record of population history, migration, and adaptation. A reference genome built mostly from one population is in essence, an incomplete map. Making genetic research more diverse is a matter of equity, and of determining whose health benefits from the genetics revolution.

Epigenetics: Genes That Can Be Switched On and Off

While the basic laws of inheritance outlined by Mendel haven't changed, our understanding of genes and our genome definitely has thanks to the burgeoning and more specialized field of Epigenetics. Epigenetics is the study of changes in gene expression that don't involve changes to the DNA sequence itself.

Lying along the DNA molecule is a second layer of structure made of up chemical tags, known as methyl tags. These tags are sensitive to any changes in the chemical environment of the cell. What can change the cellular environment? Stress, trauma, activity levels, exposure to environmental toxins, and diet can all produce changes in the cell that alter gene expression.

Think of your genome as the hardware of a computer, and the epigenome as the software. The underlying code doesn't change, but which programs are running—which genes are turned on or off—can vary dramatically from cell to cell, and over the course of lifetime.

Two major epigenetic mechanisms are **DNA methylation** which involves the addition of a chemical groups that typically silences a gene, and **histone modification**, which are changes to the proteins DNA wraps around, affecting whether a gene is accessible to be transcribed.

Identical twins are a particularly striking example. They start with identical DNA, but as they age, their epigenetic profiles diverge—shaped by different experiences, environments, and behaviors. This explains why identical twins can develop different diseases, have different personalities, and even age differently despite sharing the exact same DNA.

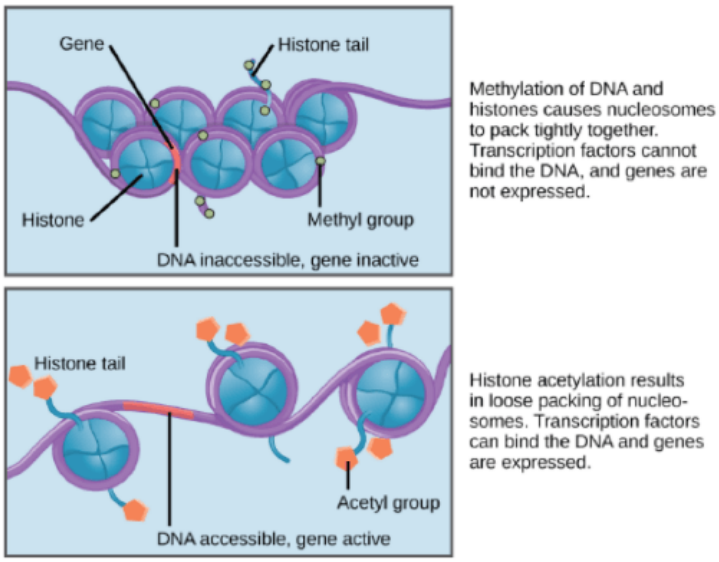


Figure 4.6.3: Different types of epigenetic histone tail modifications that can tighten (top) and loosen (bottom) the chromatin of DNA. Credit: Epigenetic Control (Biology 2e, Figure 16.7) by OpenStax is under a CC BY 4.0 License.

What epigenetics and the epigenome reveal is that our genes are very flexible and responsive to our lived experiences. Not only is there more complexity in getting from genotype to phenotype, it also introduces an infinite amount of variation.

Did You Know?

The Best Biohack is Being Human

Somewhere right now, a tech billionaire is spending millions chasing immortality. He's tracking every biomarker, freezing his plasma, swallowing fistfuls of supplements before sunrise. Meanwhile, in a village in Sardinia, Italy, an 87-year-old woman is walking uphill to tend her garden, then sitting down to a lunch of beans, bread, and fresh vegetables with three generations of her family. She's never heard the term "biohacking," and she's never set foot in a gym—she doesn't need to. The most powerful tools for a long, vital life aren't locked away in a lab, or a gym, or a protein shaker bottle. They're stitched into the fabric of ordinary life, and they always have been.



Figure 4.6.4: Kneading dough. Image by Anonymous friend of ElinorD, Public domain, via Wikimedia Commons.

In the Blue Zones, places like Okinawa, Sardinia, Ikaria, Costa Rica's Nicoya Peninsula, people don't "work out." They don't count grams of protein or chase a number on a fitness app. They stay active simply because movement is what is required as the day unfolds: walking to a neighbor's house, climbing stairs to a hillside, kneading dough, herding goats, tending a garden. Researchers studying these populations call it "natural movement," the kind that's woven into life rather than scheduled around it.

Their plates tell a similar story. Beans, not protein powder. Vegetables, not macros. Food eaten because it's in season and shared at a table, not engineered in a lab or optimized in an app. None of it is calculated, but all of it works.

We know now that our genes respond to our lived experiences. They're not a fixed script, they're more like a piano, and your daily choices decide which keys get played. Real, whole foods give your cells the raw materials to repair themselves. Natural movement signals your body to keep building strength. Time in nature lowers stress hormones that quietly age you from the inside. And real connection—a hand on your shoulder, a shared meal with friends or family, a sense of belonging—may be the most underrated longevity practice we have.



Figure 4.6.5: Gardening together. Photo by OPPO Find X5 Pro on Unsplash.

> You don’t need a lab, a gym, or a shelf full of supplements to access any of it. All you need is a walk. A vegetable. A phone call to someone you love. The future of longevity can’t be engineered in Silicon Valley or sold in a protein aisle. It’s already being lived in communities around the globe that never stopped doing it right. At the end of the day, true optimization isn’t about doing more. It’s about slowing down enough to remember what we never should have stopped doing.

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4.7: Genetic Testing and Genetic Engineering

Genetic Science Today

To assist with public health efforts, newborn screening for genetic diseases has been available in the United States for 50 years. One of the first available genetic tests was used to confirm a phenylketonuria (PKU) diagnosis in infants, a condition that is easily managed with a dietary change. Today, each state decides which genes are included on its newborn screening panel, and some states even have programs to help families navigate medical follow-up care.

Since those early days, the genetic testing industry has exploded. There are now hundreds of laboratories offering tests for a few thousand different genes, results than can inform medical decisions for both infants and adults. Both rapid improvement in sequencing technology and a steep drop in cost made this possible. Genetic testing has also moved out of the clinic and into everyday life. You can now order a DNA test online without seeing or consulting with medical professionals.

Clinical Testing

Clinical genetic tests help patients make medically informed decisions about family planning and health. Applications include support for in vitro fertilization (IVF), embryo genetic screening, and personalized medicine, such as matching cancer patients to therapies most likely to work for their specific tumor. Because the stakes are high, clinical laboratories in the United States must follow the Clinical Laboratory Improvement Amendments (CILA), a set of federal standards designed to ensure accurate results.

One major benefit of clinical genetic testing is access to genetic counselors who are professionals with specialized training in medical genetics and counseling. If someone has a family history of a genetic disease, a physician may recommend carrier screening to assess the risk of passing that condition on to a child. Genetic counselors help patients interpret results and provide support as they work through what can be emotionally difficult decisions.

Direct-to-Consumer (DTC) Genetic Testing

Direct-to-consumer (DTC) genetic testing—DNA testing purchased and used without a doctor or genetic counselor involved—has become hugely popular. Companies market these tests around the idea of personal empowerment: the more you know about your DNA, the better choices you can make. A test might flag a slightly elevated risk for celiac disease, prompting someone to try a gluten-free diet, or it might detect a **pathogenic** *BRCA1* or *BRCA2* variant linked to cancer risk, prompting a visit to a physician for follow-up clinical testing. DTC companies also sell tests purely for fun or lifestyle purposes, such as ancestry breakdowns or “personalized” fitness and nutrition reports.

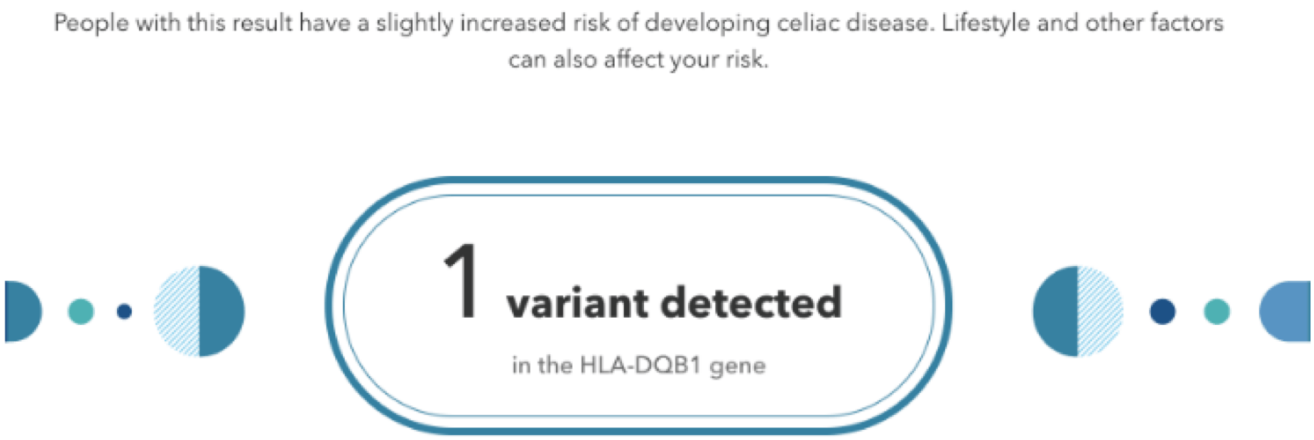


Figure 4.7.1: A positive result for a genetic allele associated with an increased risk for celiac disease. Credit: Positive carrier result for celiac disease allele by Hayley Mann is under a CC BY-NC 4.0 License.

Because DTC testing skips genetic counselors and faces looser regulation than clinical labs, it has generated real controversy. When the company 23andMe began offering health-related results in 2007, the FDA stepped in by 2013, concerned that customers were receiving complex medical information, like Alzheimer's disease risk, without professional guidance to help interpret it. Critics worried this could create unnecessary anxiety, sometimes called the "burden of knowing," or lead people to make medical decisions they didn't fully understand. 23andMe eventually worked with the FDA to gain approval for a limited set of health reports, requiring customers to complete educational modules before viewing certain results. At the same time, some customers have used these results to seek out beneficial medical care they otherwise wouldn't have pursued.

The 23andMe story took a dramatic turn in 2025, however, and it raises a cautionary question that goes beyond medical interpretation: what happens to your most intimate biological information when the company holding it goes out of business? After years of financial losses, a 2023 data breach that exposed the genetic and personal data of nearly 7 million users, and a workforce reduction of 40%, 23andMe filed for bankruptcy in March 2025 (Al-Hindi and Henn 2025). A U.S. bankruptcy court ruled that the company's genetic database, containing information from roughly 15 million customers, could be sold as a corporate asset. Attorneys general in multiple states urged residents to delete their data immediately. The database was ultimately acquired for $305 million by TTAM Research Institute, a nonprofit created and controlled by 23andMe's own co-founder. Legal scholars have since called the bankruptcy an "inflection point" for the DTC genetics industry, pointing out that current bankruptcy law contains no explicit protections for genetic data—meaning your DNA profile can legally change hands without your meaningful consent. The case has renewed calls for federal legislation that treats genetic data differently from other personal information (Branch 2025).



Figure 4.7.2: Ancestry.com test kit. Wonder Who I Am? Image by Lisa Zins, CC BY 2.0, via Wikimedia Commons.

Ancestry tests raise a related set of concerns. They sort a customer's DNA into population categories, but genetic variants rarely belong exclusively to one group, and the boundaries of these "populations" are defined by the companies themselves rather than by biology.



Figure 4.7.3: An example of ancestry percentage results provided to customers. Credit: DNA ancestry percentage test results by Hayley Mann is under a CC BY-NC 4.0 License.

An allele labeled “Irish” for example, likely existed long before the country of Ireland did. Another consideration is that someone’s identity need not include biological relationships. In using these tests, customers do have the option to connect with newfound genetic relatives online which can be a wonderful experience for some people and a painful one for others.

The Golden State Killer: When Ancestry Tests Solve Crimes

Law enforcement has also demonstrated just how powerful, and how privacy threatening, these consumer databases can be. The most famous example is the Golden State Killer case. Joseph James DeAngelo had terrorized California for over a decade in the 1970s and 80s, committing more than 120 burglaries, 51 sexual assaults, and 13 murders before going unidentified for decades. In 2018, investigators uploaded DNA from an old crime scene to GEDmatch, a free public database where anyone can share results from consumer DNA tests to search for relatives. The search identified distant cousins of DeAngelo. These relatives had simply taken an ancestry test out of curiosity, but detectives used that family connection, combined with geneaological records and other details, to build a family tree and eventually zero in on DeAngelo. They confirmed the match with his discarded DNA, arrested him, and he ultimately pleaded guilty in 2020 and was sentenced to life in prison. The case was celebrated as a breakthrough for cold-case investigations, but it also alarmed privacy advocates. None of DeAngelo’s relatives had agreed to help law enforcement identify a family member. By uploading their own DNA to a public database, they had unknowingly made themselves, and everyone genetically connected to them, searchable by police. Still, tens of millions of people worldwide have now had their DNA tested, and the multi-billion dollar genomics market continues to grow.

Genetic Engineering: Editing the Code of Life

Genetic testing tells us what’s already written in an organism’s DNA. **Genetic engineering** goes a step further by changing DNA on purpose. This field has moved from science fiction to everyday reality astonishingly fast, and it raises some of the most important ethical questions in modern biology and society.

Genetically Modified vs. Genetically Engineered: What’s the Difference?

People often use “GMO” (genetically modified organism) and “genetically engineered” interchangeably, but it’s worth pulling these terms and processes apart.

Humans have been modifying the genetics of plants and animals for thousands of years through **artificial selection** by choosing which individuals get to reproduce based on traits we want. Cross-breeding corn varieties to get sweeter kernels, or breeding

dogs or cats for specific traits, are both forms of genetic modification, but they work *within* a species' existing gene pool and happen gradually over many generations.



Figure 4.7.4: : From left, female and male British shorthair kittens. The British shorthair breed is known for its short, dense coat, rounded head and face, small ears, and large, round eyes. Images by Kalil Mitchell and Rachel Mitchell.

Transgenic engineering, or genetically engineered organisms (GEOs), is something different. Scientists take a gene from one species, sometimes from a completely different kingdom of life, and insert it directly into another organism's genome. One example comes from a genetically engineered salmon that contains a growth hormone gene from a Chinook salmon paired with a genetic "on switch" from an eel-like fish called the ocean pout, allowing it to grow to market size in about half the normal time (U.S. FDA AquAdvantage Salmon Fact Sheet, 2025).

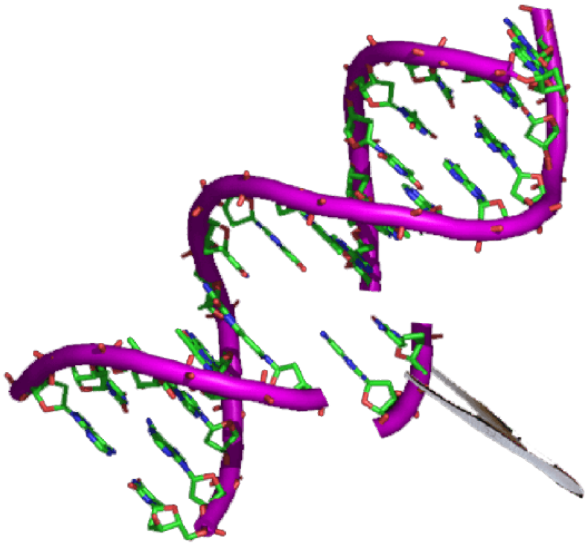


Figure 4.7.5: Genetic engineering with CRISPR-like tool. Image by Ciencias EspañolasKoS, CC BY-SA 3.0 via Wikimedia Commons.

More recently, gene editing tools like CRISPR have introduced a third category. Rather than inserting foreign DNA, CRISPR works like a precise pair of molecular scissors, allowing scientists to cut, delete, or rewrite an organism's *own* genes. A non-browning mushroom approved in the U.S. a few years ago was created this way. Researchers simply switched off the gene responsible for browning without adding any new DNA at all. Because no foreign genes are introduced, gene-edited organisms like this one are often regulated quite differently than transgenic GEOs, which has sparked its own debate about whether existing labeling laws make sense (Waltz 2016).

Cloning: Copying Life

Cloning produces a genetically identical copy of an existing organism, most famously demonstrated with Dolly the sheep in 1996. While cloning captured the public imagination and inspired a number of science fiction thrillers, it has found a genuinely serious

application in conservation biology.

Can Cloning Save an Endangered Species?



Figure 4.7.6: Endangered Black-footed Ferrets. Image by Kimberly Fraser / USFWS, Public domain, via Wikimedia Commons.

The black-footed ferret is North America's only native ferret species and one of the continent's most endangered mammals. By the 1980s, the entire surviving population descended from just seven individuals, leaving the species dangerously low on genetic diversity. Scientists at the San Diego Zoo Wildlife Alliance's Frozen Zoo had preserved tissue from a ferret named Willa, who died in 1988 without leaving any descendants. Willa's genetic material contained roughly three times more unique variations than found in the surviving population—a treasure trove of lost diversity sitting in a freezer for over three decades. Researchers used Willa's preserved tissue to produce three clones. The first, Elizabeth Ann, was born in December 2020 as the first cloned endangered species native to North America. Her fellow clones, Antonia and Noreen, followed in May 2023. In June 2024, Antonia became the first cloned animal of any endangered species to successfully reproduce with a male black-footed ferret from an existing captive population, giving birth to two surviving kits. Unlike a clone, Antonia's kits are not genetically identical to Willa. They carry Willa's rare genetic material blended with that of their father, which is precisely the outcome conservationists were hoping for.

By summer 2025, four more litters had been born from Antonia, Noreen, and Antonia's own offspring, bringing the total number of ferrets carrying Willa's genes to 15 individuals. Sadly, both Elizabeth Ann and Noreen passed away in 2025, but the program continues through Antonia and her growing line of descendants. Willa's story is a reminder that the tools of modern genetics and the dedication of conservation biologists, working together, can accomplish can turn the tide for species on the edge of extinction.

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Cloning has also become a commercial service. Companies now offer to clone people's deceased pets (for a considerable price), which raises its own interesting question: does a cloned pet have the same personality as the original? As you've learned from epigenetics, that's not necessarily the case.

De-Extinction: Can We Bring Back Extinct Species and Should We?

Cloning and gene editing are now bringing what once seemed like science fiction to life: the revival of extinct species. The company leading this effort is Colossal Biosciences, a biotech firm valued at $10 billion and whose tagline, “Forever is Temporary,” signals just how ambitious its goals are. Colossal has announced projects targeting the woolly mammoth, the dodo, and the Tasmanian tiger.

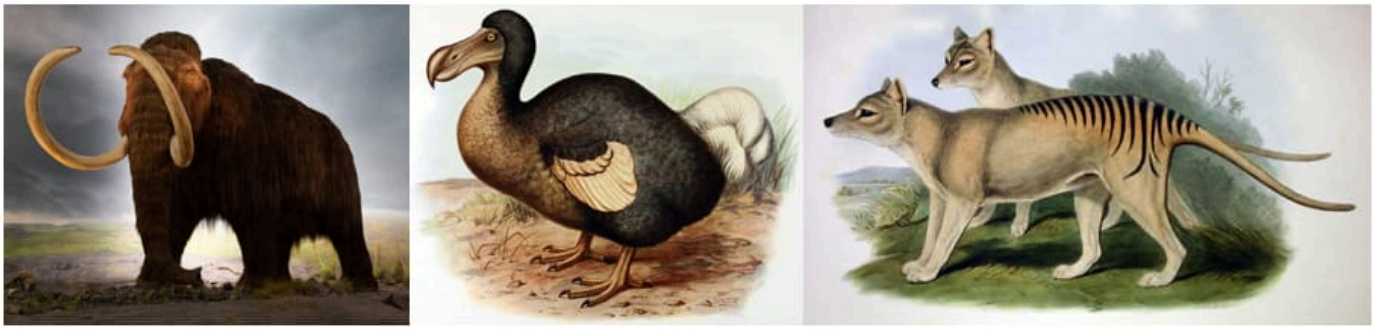


Figure $4.7.7a - c$: Extinct animals. a) Woolly Mammoth. Image by Thomas Quine, CC BY 2.0 via Wikimedia Commons; b) Dodo. Image by Frederick William Frohawk (16 July 1861 - 10 December 1946), an English zoological artist and lepidopterist., Public domain, via Wikimedia Commons; c) Tasmanian tigers. Image is in the public domain via Wikimedia Commons.

Their most headline-grabbing achievement to date involves the dire wolf, a large predator that roamed the Americas during the last ice age before going extinct roughly 10,000 years ago. In April of 2025, Colossal announced the births of three pups named Romulus, Remus, and Khaleesi, whose gray wolf DNA had been edited in some places and designed in others to mimic gene expressions found in ancient dire wolf DNA extracted from a preserved tooth and skull. The resulting animals display several dire wolf traits, including distinctively shaggy white fur.

But are they *really* dire wolves? Most scientists say not, or at least, not exactly. As one paleogeneticist put it, what Colossal produced is essentially a genetically engineered designer gray wolf. This distinction matters because if de-extinction is real, then extinction is no longer permanent. This has some conservationists worried that this could reduce public urgency around protecting species that are endangered *right now*. Indigenous scholars have raised additional concerns: from a Māori perspective rooted in the concept of *kaitiakitanga*—humanity’s duty to care for the natural world—recreating a species without first healing the environment and communities it was part of misses the point entirely (Golembiewski 2026).

Colossal’s chief science officer, Beth Shapiro, pushes back on the idea that de-extinction competes with conservation. She argues that the excitement generated by these projects has attracted investment in tools that are actively helping save elephants, corals, and other living species. At the same time, behavioral scientists studying public attitudes caution that the spectacle of “bringing back” a dramatic extinct animal might give people the false impression that extinction is reversible—a misunderstanding that a 2023 global survey found already existed in roughly half of respondents, *before* the dire wolf announcement.

The debate over de-extinction is, at its core, a debate about what we owe the natural world, how we define a species, and whether technological ingenuity can substitute for the harder work of protecting ecosystems in the first place.

Gene-Edited and “Designer” Babies

The most ethically charged frontier of genetic engineering involves editing the genomes of human embryos. It’s important to distinguish between two very different applications here.

Somatic gene editing changes the DNA of a living person’s cells but is not passed on to their children. In 2025, doctors at Children’s Hospital of Philadelphia used a custom-designed CRISPR therapy to correct a life-threatening metabolic mutation in an infant known as “KJ,” who was born with a rare condition in which the liver cannot properly process ammonia, allowing it to build up to toxic levels. KJ received his first infusion of the personalized therapy in February 2025, making him the first person in history to receive a customized gene editing drug designed specifically for his individual genetic variant (Musunuru, et al. 2025; The Economist, 2025). By February 2026, one year later, KJ had achieved meaningful milestones including walking and talking, and continues to grow (Children’s Hospital of Philadelphia, 2026). This kind of personalized gene therapy is increasingly seen as a legitimate medical treatment, similar in principle to other advanced therapies, though still extraordinarily expensive and currently

available to very few patients.

Germline editing, by contrast, alters the DNA of an embryo, sperm, or egg in a way that would be inherited by all future generations. This is where “designer babies” enter the conversation. In 2018, Chinese scientist He Jiankui announced that he had used CRISPR to edit the embryos of twin girls, attempting to make them resistant to HIV. The scientific community reacted with near-universal condemnation and He was sentenced to prison for violating research ethics regulations (McCurry 2024).



Figure 4.7.8: He Jiankui at Second International Summit on Human Genome Editing. Image by VOA - Iris Tong, Public domain, via Wikimedia Commons.

You might think that scandal would end the conversation, but it hasn’t. New biotech startups announced plans to pursue embryo editing research, driven mostly by interest from tech billionaires (The Economist, 2025). Most scientists agree that the techniques still aren’t safe or well-understood enough for clinical use, and a number of countries have banned reproductive germline editing outright. But the debate over *whether* and *when* it might ever be appropriate for preventing genetic diseases versus selecting to enhance traits like intelligence, or appearance, is very much alive.

Big Business, Big Questions

Genetic engineering is now a massive global industry, spanning agriculture, pharmaceuticals, conservation, and reproductive medicine. Across the examples we’ve explored here, the same fundamental ethical questions tend to arise:

Safety and unintended consequences. Editing DNA can have effects beyond the targeted gene, and our understanding of how genes interact with each other and the environment is still incomplete.

Access and equity. Advanced genetic therapies and reproductive technologies are expensive. If only wealthy individuals can access embryo selection or genetic enhancement, could this widen existing social inequalities or even create new forms of biological inequality?

Consent across generations. Germline edits don’t just affect one person; they’re passed down to children, grandchildren, and beyond, none of whom can consent to the change.

Where do we draw the line? Most people would be comfortable with using genetic technology to treat or prevent serious disease. Far fewer might be comfortable using it to select for traits like eye color, height, or athletic ability, yet the same underlying tools could potentially do both. Drawing that line, and deciding who gets to draw it, is as much a question for anthropologists, bioethicists, and policymakers as it is for scientists.



Figure 4.7.9: Build a Baby? Designing a future child with a menu of traits. Image produced by Google Gemini.

As you continue through this course, keep these themes in mind. Understanding how DNA works—and how we're increasingly able to read, copy, and rewrite it—is essential not only for understanding evolution and human variation (covered in the chapters ahead), but for thinking critically about the kind of future we want these technologies to help build.

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4.8: Key Terms

Key Terms

Agglutination – a reaction in which particles, such as red blood cells or bacteria, clump together

Allele – A nonidentical DNA sequence found in the same gene location on a homologous chromosome, or gene copy, that codes for the same trait but produces a different phenotype.

Amino acid – organic molecules that serve as the fundamental building blocks of proteins.

Ancient DNA (aDNA) – DNA that is extracted from organic remains and that often dates from hundreds to thousands of years ago. Also, aDNA is typically degraded (i.e., damaged) due to exposure to the elements such as heat, acidity, and humidity.

Antibodies – Immune-related proteins that can detect and bind to foreign substances in the blood such as pathogens.

Antigens – any substance, usually a protein or sugar, that the immune system identifies as foreign or harmful

Artificial Selection – also known as selective breeding, refers to humans deliberately controlling reproduction to produce specific traits in plants in animals

Autosomal - Refers to a pattern of inheritance in which an allele is located on an autosome (non sex chromosome.)

Chromatin - DNA wrapped around histone complexes. During cell division, chromatin becomes a condensed chromosome.

Chromosome - DNA molecule that is wrapped around protein complexes, including histones.

Codon – A sequence that comprises three DNA nucleotides that together code for a protein.

DNA (Deoxyribonucleic acid) - A molecule that carries the hereditary information passed down from parents to offspring. DNA can be described as a “double helix”’ shape. It includes two chains of nucleotides held together by hydrogen bonds with a sugar phosphate backbone.

DNA Methylation – Methyl groups bind DNA, which modifies the transcriptional activity of a gene by turning it “on” or “off.”

Dominant – Refers to an allele for which one copy is sufficient to be visible in the phenotype.

Double helix – the physical, twisted-ladder structure of DNA

Epigenetics – Changes in gene expression that do not result in a change of the underlying DNA sequence. These changes typically involve DNA methylation and histone modifications. These changes are reversible and can also be inherited by the next generation.

Epigenome – a set of chemical compounds along the DNA molecule that can alter gene expression

Frameshift mutation – a genetic mutation caused by the insertion or deletion of nucleotide bases in a DNA sequence

Gametes – also called the reproductive or sex cells (sperm in males, eggs in females), are specialized cells containing half the normal number of chromosomes that unite during sexual reproduction.

Gene – the basic physical and functional unit of heredity; a segment of DNA that contains protein-coding information and various regulatory and noncoding regions.

Genetically modified organism – any living thing whose genetic material has changed due to selective breeding and hybridization

Genome – All the genetic information of an organism.

Genotype – The combination of two alleles that code for or are associated with the same gene.

Germline editing – a genetic modification technique that alters the DNA of reproductive cells.

Germline mutation – a genetic alteration in a parent's reproductive cells (gametes) that become incorporated into the DNA of the offspring's cells and body.

Helicase – A protein that breaks the hydrogen bonds that hold double-stranded DNA together.

Heterozygous – Genotype that consists of two different alleles.

Histone modification – chemical changes to histone proteins that act as an epigenetic control system, influencing gene activity and expression

Histones - Proteins that DNA wraps around to assist with DNA organization within the nucleus.

Homologous chromosomes – A matching pair of chromosomes wherein one chromosome is maternally inherited and the other is paternally inherited.

Homozygous – Genotype that consists of two identical alleles.

Horizontal (lateral) gene transfer – the movement of genetic material between organisms through mechanisms other than traditional reproduction (parent to offspring), allowing different, sometimes distantly related, organisms to share genetic traits directly

Meiosis – The process that gametes undergo to divide. The end of meiosis results in four haploid daughter cells.

Mitosis – The process that somatic cells undergo to divide. The end of mitosis results in two diploid daughter cells.

Molecular anthropologists - Individuals who use molecular techniques (primarily genetics) to compare ancient and modern populations and to study living populations of humans and nonhuman primates.

Molecular geneticists - Biologists that study the structure and function of genes.

Monogenic trait – a trait that is controlled by one gene

Mutagens – any physical or chemical agent that permanently alters genetic material (DNA or RNA), increasing the frequency of mutations.

Mutation – A nucleotide sequence variation from the template DNA strand that can occur during replication. Mutations can also happen during recombination.

Nucleotide – The basic structural component of nucleic acids, which includes DNA (A, T, C, and G) and RNA (A, U, C, and G).

Nucleus – Double-membrane cellular organelle that helps protect DNA and also regulates nuclear activities.

Pathogenic - A genetic mutation (i.e., allele) that has a harmful phenotypic disease-causing effect.

Pedigree - A diagram of family relationships that indicates which members may have or carry certain genetic and/or phenotypic traits.

Phenotype – The physical appearance of a given trait.

Polygenic trait – A phenotype that is controlled by two or more genes.

Polymerase - Enzyme that adds nucleotides to existing nucleic acid strands during DNA replication. These enzymes can be distinguished by their processivity (e.g., DNA replication).

Recessive – Refers to an allele whose effect is not normally seen unless two copies are present in an individual's genotype.

RNA (Ribonucleic acid) – Single-stranded nucleic acid molecule.There are different RNAs found within cells and they perform a

variety of functions, such as cell signaling and involvement in protein synthesis.

Semi-conservative replication - DNA replication in which new DNA is replicated from an existing DNA template strand.

Sex-linked (X-linked) gene – Refers to a pattern of inheritance where the allele is located on the X or Y chromosome.

Somatic gene editing – process of altering the DNA of targeted, non-reproductive cells to treat disease

Telomere - A compound structure located at the ends of chromosomes to help protect the chromosomes from degradation after every round of cell division.

Transcription – The process by which DNA nucleotides (within a gene) are copied, which results in a messenger RNA molecule.

Transgenic genetic engineering (genetically engineered organisms) – an organism whose genetic material has been altered using biotechnology by adding, removing, or changing specific genes

Translation – The process by which messenger RNA codons are read and amino acids are “chained together” to form proteins.

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5: EVOLUTIONARY PROCESSES AND GENES IN POPULATIONS

5.1: Population Genetics- Thinking About Evolution at the Right Scale
5.2: The Four Forces of Evolution
5.3: Key Terms
5.4: References and Attributions

Learning Objectives

- Outline a 21st-century perspective of the Modern Synthesis.
- Define populations and population genetics.
- Identify and distinguish between the forces of evolution and become familiar with examples of each.
- Explain how allele frequencies can be used to study evolution as it happens.

The Modern Synthesis

Darwin understood natural selection, but he didn't know about genes or DNA. Gregor Mendel worked out the basic rules of inheritance, but his work was largely ignored during his lifetime and not widely known until Darwin's death. Scientists brought these two bodies of knowledge together into what is now called the Modern Synthesis.

The Modern Synthesis united Darwin's theory of natural selection with Mendelian genetics and, eventually, population genetics. It produced our current understanding of evolution: a change in allele frequencies in populations over time, driven by the four forces of mutation, genetic drift, gene flow and natural selection. Each force was rigorously tested and retested through decades of experimental and observational research. That process of testing and refinement is what makes the theory of evolution one of the most thoroughly supported explanatory frameworks in all of science.

It's hard for us, with our typical human life spans of less than 100 years, to imagine all the way back, 3.8 billion years ago, to the **origins of life**. Scientists still study and debate how life came into being and whether it originated on Earth or in some other region of the universe (including some scientists who believe that studying evolution can reveal the complex processes that were set in motion by God or a higher power). What we do know is that a living single-celled organism was present on Earth during the early stages of our planet's existence. This organism had the potential to reproduce by making copies of itself, just like bacteria, many amoebae, and our own living cells today. In fact, with modern technologies, we can now trace genetic lineages, or **phylogenies**, and determine the relationships between all of today's living organisms—eukaryotes (animals, plants, fungi, etc.), archaea, and bacteria—on the branches of the **phylogenetic tree of life** (Figure 5.1).

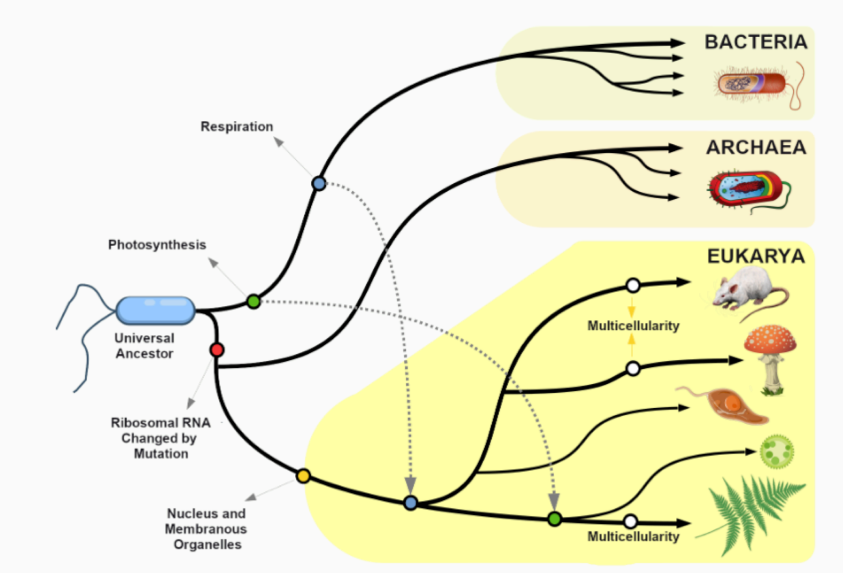


Figure 5.1: Phylogenetic tree of life illustrating probable relationships between the single-celled Last Universal Common Ancestor (LUCA) and select examples of bacteria, archaea, and eukaryotes. Major evolutionary developments, including independent evolution of multicellularity, photosynthesis, and respiration, are indicated along the branches. Credit: Cladograma dos Dominios e Reinos by MarceloTeles has been modified (English labels replace Portuguese) and is under a CC BY-SA 4.0 License.

Looking at the common sequences in modern genomes, we can even make educated guesses about the likely genetic sequence of the **Last Universal Common Ancestor (LUCA)** of all living things. And that brings us to the central question Darwin was trying to answer: How do new species originate? In the grand scheme of life, how did a single microscopic organism give rise to all of the amazing diversity of life that now fills every corner of our planet today? The answer lies in a set of processes called the forces of evolution.

Chapter Overview

This chapter explores those forces: **mutation**, **genetic drift**, **gene flow** and **natural selection**. Together, they explain how genetic variation arises, how it spreads or disappears within populations, and how over vast stretches of time, they can lead to new species. These forces are what shape the bacteria that become resistant to antibiotics, the insect pests that cause farmers to search for ever more potent pesticides, and even our own human history as a species.

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5.1: Population Genetics- Thinking About Evolution at the Right Scale

Introduction

One of the most important developments in understanding evolutionary change was the realization that individuals don't evolve; *populations* do. As you've learned, lifestyle choices can influence how our genes are *expressed*, but that's epigenetics, and it doesn't change the underlying DNA itself. Evolution is a different, slower process. It unfolds at the population level, across multiple generations. What evolves over time isn't any one person's genome, but the **gene pool**—the collective set of alleles across all individuals in a population.

In biology, a **population** is defined as a group of individuals of the same species who live close enough to one another to breed and produce **viable offspring** together. To really understand evolution, we need to zoom in even further, to the level of genes.

Recall that a gene is a stretch of DNA that carries instructions for making a specific protein. Most genes come in multiple versions called **alleles**. It might help to think of a gene as a recipe and alleles as slightly different versions of that recipe, each producing a result that is similar, but not quite identical. Because humans inherit one copy of each gene from each parent, we each carry two alleles for every gene on our non-sex chromosomes. If both alleles are the same, the **genotype** is **homozygous** for that gene. If the two alleles differ, the genotype is **heterozygous**.

Together, all of the alleles present in a breeding population form what's known as the **gene pool.** Tracking how the frequencies of those alleles change across generations is how scientists measure evolution over time.

Allele Frequencies and the Definition of Evolution

The modern, scientific definition of evolution is: a change in **allele frequencies** in a population over time. This means that evolutionary change is fundamentally a genetic process. It's not just "change" in a general sense, it's measurable shift in the proportions of different genetic variations across generations.

First, we need to know what an allele frequency is. This is simply the proportion of a particular allele among all the copies of that gene in a population. If, for example, 40 out of 100 copies of a particular gene in a population are the "A" allele, then the frequency of the A allele is 0.4 (40%). If that proportion shifts in the next generation, then technically, evolution has occurred. This definition gives scientists a precise, testable way to study evolutionary change.

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5.2: The Four Forces of Evolution

Four mechanisms drive changes in allele frequencies: **genetic drift, gene flow, natural selection** and **mutation**. These are often called the "forces of evolution." The first three redistribute or alter the existing variation within and between populations while mutation is the only one that actually creates brand-new genetic variation.

Mutation: The Original Source of All Variation

We begin with mutation because this serves as the original source of all of the genetic variation found in every living thing. A mutation is any change in the sequence of DNA bases—adenine, thymine, cytosine, and guanine. As you learned in Chapter 4, these bases are strung together in a specific order, encoding genetic information needed by the cell. When a cell copies its DNA in preparation for dividing, mistakes can sometimes happen. A base might be swapped for a different one, a small section might be duplicated, or an entire segment might be deleted. Any of these changes is considered to be a mutation.

Mutations can also be triggered by outside influences. Ultraviolet (UV) radiation from the sun, for example, can cause adjacent thymine bases in a DNA strand to bond together abnormally. This is why excessive sun exposure raises the risk of skin cancer. Radiation and certain chemicals can also damage DNA. Whatever the cause, the outcome is the same: the cell ends up with a DNA sequence that differs from the original.

Which Mutations Matter for Evolution?

Not all mutations have evolutionary significance. Our bodies are made up of two broad categories of cells: **somatic cells,** which make up the organs, skin, muscles, and other tissues, and **gametes**, the reproductive cells (sperm and eggs). Most of our mutations exist in somatic cells and only affect the individual who carries them so will not be passed to the next generation. Mutations in gametes, however, can be inherited. When a mutation first appears in a gamete and is then passed on to an offspring, it is called a **spontaneous mutation**. If that individual goes on to reproduce, their offspring inherit it as well, and it becomes part of the family lineage, making it an **inherited mutation**.

The Good, the Bad, and the Neutral

While it's common to associate mutations with either catastrophic outcomes, such as cancer or genetic disease, the reality of their impact is a bit more nuanced. Most mutations fall into one of three categories. Many are neutral, meaning they have no detectable effect on the organism. Perhaps the mutation falls in a region of DNA that doesn't code for any protein, or perhaps it alters a **codon** in a way that still produces the same amino acid. The organism carries the change in its genes, but is not affected by it.

Some mutations are known to harm an organism's ability to survive and reproduce. **Tay-Sachs disease**, for example, is caused by a mutation in a gene that produces an enzyme responsible for breaking down fatty substances in the brain and nerve cells. Without a functioning version of this enzyme, those substances accumulate to toxic levels, causing progressive neurological damage. Children born with two copies of the Tay-Sachs allele typically do not survive past early childhood (Mayo Clinic). Mutations so damaging that they prevent survival altogether are called lethal mutations.

But some mutations can be beneficial. A beneficial mutation increases an organism's chances of surviving, reproducing, or both in a given environment. The ability of some insects to resist a pesticide, for example, often traces back to a single beneficial mutation. Dog breeds adapted to cold climates, such as malamutes and huskies, have mutations that produce thick, insulating coats, while those adapted to warmer climates, like Chihuahuas, carry mutations that keep their coats thin.



Figure 5.2.1$a-b$: Coat differences between dogs due to beneficial mutations. a) Greenland Husky Sled dogs and b) a Chihuahua. a) Image by: Markus Trienke, CC BY-SA 2.0 via Wikimedia Commons; b) Image by: Banne27, CC BY-SA 4.0 via Wikimedia Commons.

We all carry genetic mutations within our genome. Every time our cells divide and replicate through the process of mitosis, those mutations are also copied into all of our cells, serving as our personal reservoir of genetic diversity. In an ever-changing world, this can be a big advantage. Perhaps somewhere in there could be the genes that might help you resist a harmful virus or any other unexpected change in the environment—physical or cultural. In fact, this is the story of the evolution of **lactase persistence** that we will examine in more detail later in this chapter.

Sickle Cell and the Power of One Mutation: A Case Study

Sickle cell anemia is a genetic disease with severe symptoms, including pain and anemia. The disease is carried by a mutated version of the gene that helps makes hemoglobin which is a protein that carries oxygen in red blood cells. People with two copies of the sickle cell allele have the disease. People who carry only one copy of the sickle allele do not have the disease, but may pass the allele on to their children.

The mutations that cause sickle cell anemia have been extensively studied and demonstrate how the effects of mutations can be traced from the DNA level up to the level of the whole organism. If someone carries only one copy of the sickle cell allele, she will not have the disease, but the gene that she carries will still affect her, her cells, and her proteins as can below.

At the DNA level, just one base is different from the typical version of the gene.

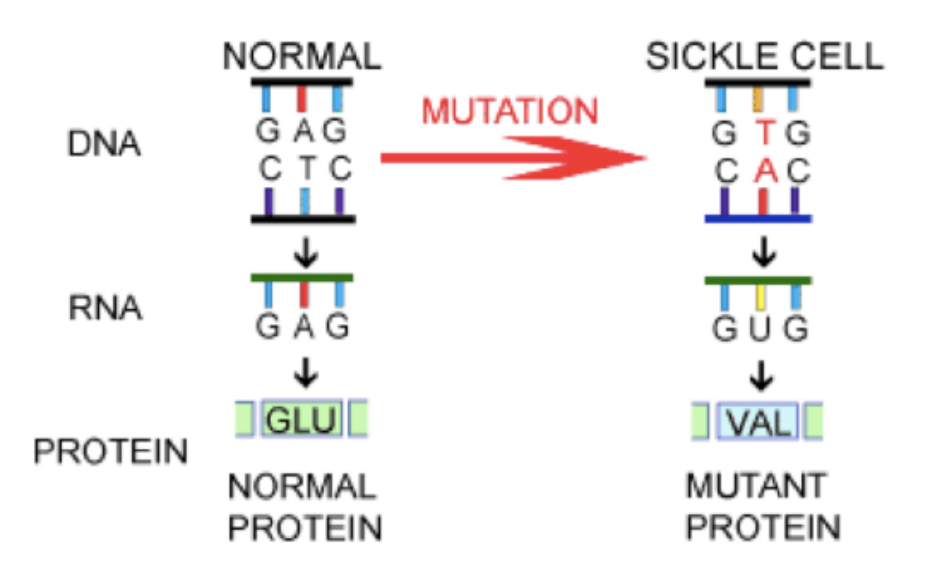


Figure 5.2.2: DNA level changes from mutation to the hemoglobin gene. Image credit: DNA mutation for hemoglobin. © UC Museum of Paleontology Understanding Evolution, www.understandingevolution.org and is used under a Attribution-NonCommercial-ShareAlike 4.0 (BY-NC-SA 4.0) Creative Commons License.

At the protein level, this causes the hemoglobin molecule to be shaped slightly differently, causing it to clump together under low-oxygen conditions.

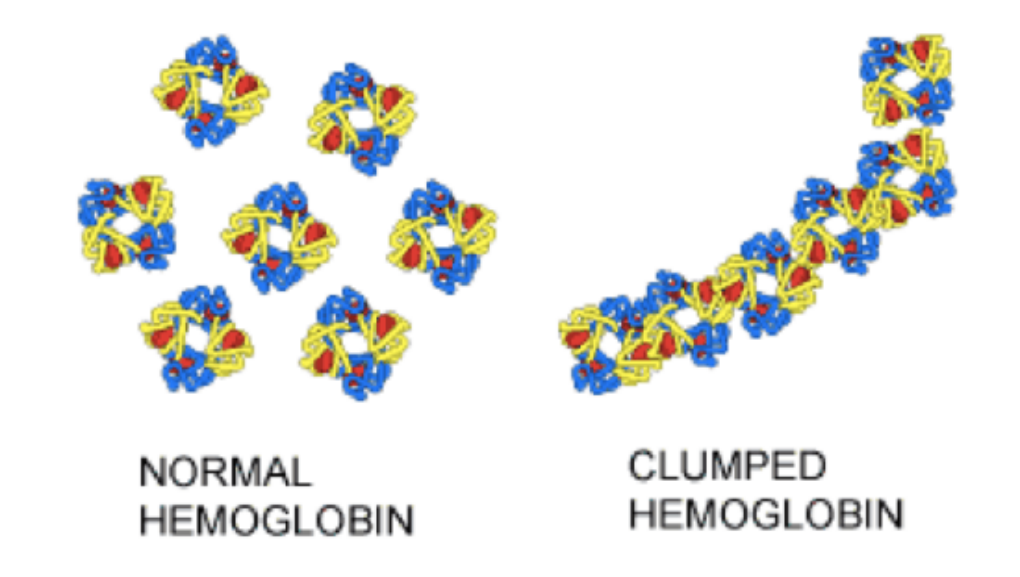


Figure 5.2.3: Protein level changes that cause a change in the structure of the hemoglobin molecule. Image credit: Hemoglobin molecule comparisons. © UC Museum of Paleontology Understanding Evolution, www.understandingevolution.org and is used under a Attribution-NonCommercial-ShareAlike 4.0 (BY-NC-SA 4.0) Creative Commons License.

At the cellular level, red blood cells carrying this abnormal hemoglobin form into a rigid, crescent or “sickle” shape, which can block small blood vessels.

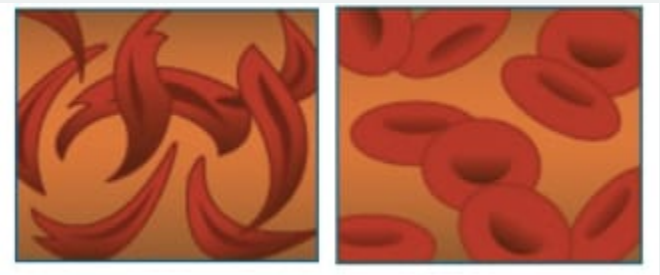


Figure 5.2.4: Sickled red blood cells on the left, and normal red blood cells on the right. Image credit: Sickled and normal red blood cells © UC Museum of Paleontology Understanding Evolution, www.understandingevolution.org and is used under a Attribution-NonCommercial-ShareAlike 4.0 (BY-NC-SA 4.0) Creative Commons License.

At the level of the whole organism, a person with *two copies* of the sickle cell allele experiences painful episodes of fatigue and anemia.

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

HHMI Biointeractive. (2018, November 28). *Sickle Cell Disease | HHMI Biointeractive Video*. [Video]. YouTube. https://www.youtube.com/watch?v=Y66B7PWrE00&t=59s

So why has this mutation persisted in human populations? In regions where **malaria** is common, carrying one copy of the sickle cell allele is actually protective. The malaria parasite that invades red blood cells cannot complete its life cycle effectively inside sickle-shaped cells. A person who carried one normal allele and one sickle cell allele does not have the disease and gains protection against malaria. In malaria-prone regions of the world, having one copy of this allele has been a significant survival advantage and is a surprising example of how the same mutation can be harmful in one context and beneficial in another.

Genetic Drift: Evolution by Chance

Not all evolutionary change is driven by survival advantages. Sometimes allele frequencies shift simply by chance. This process is called **genetic drift**, or the random fluctuations in allele frequencies from one generation to the next. These changes have nothing to do with whether one allele is more or less useful than another. In a large population, random fluctuations can more easily cancel each other out, keeping allele frequencies relatively stable. In small populations, though, random events can have an outsized effect. If, for example, the population carries more recessive alleles, then recessive traits, including harmful ones, could be expressed with greater frequency, dramatically affecting the phenotypes found in this population.

Population Bottlenecks

A population bottleneck occurs when a population is drastically reduced in size by some catastrophic event such as a natural disaster, a disease outbreak, or habitat destruction. The survivors aren't necessarily the fittest, just the luckiest. Their allele frequencies, by chance, may be quite different from those of the original population.



Figure 5.2.5: Population bottleneck of beetles due to random event. © UC Museum of Paleontology Understanding Evolution, www.understandingevolution.org and is used under a Attribution-NonCommercial-ShareAlike 4.0 (BY-NC-SA 4.0) Creative Commons License.

The Imperiled Southern Resident Orcas: When A Genetic Bottleneck Meets a Changing World

All killer whales belong to the same species, *Orcinus orca*, but they have diverged into distinct **ecotypes**—groups separated by diet, behavior, and culture—and which, crucially, don't interbreed with each other even when they share the same waters. The southern residents of the Salish Sea in the Pacific Northwest are one such group. Made up of just 74 individuals, they are organized into family pods and have their own dialect, their own social traditions, and an exclusive preference for Chinook salmon. By not exchanging genes with neighboring orca populations, they are essentially, speciating—becoming genetically distinct.



Figure 5.2.6: Family pod of southern resident orcas of the Pacific Northwest. Image is in the public domain via Wikimedia Commons.

Now, that isolation has become a serious problem. The southern residents have passed through two severe bottlenecks within the past 40 years. In the 1960s and 70s, aquariums captured or killed more than 50 individuals for display, reducing the population to just 71 animals. Their numbers partially recovered to 98 by the mid-1990s, but then a second, slower crisis began to unfold. The Chinook salmon the orcas depend on experienced a precipitous decline due to dams, habitat loss, and overfishing. A population already small from the capture era now faces chronic starvation and it's showing up in some sad and devastating ways. Malnourished females frequently miscarry or lose calves in their first year.

The evolutionary consequences of a bottleneck compound quickly in a population this size. With so few individuals—and a social structure in which offspring stay with their mothers for life, further limiting unrelated breeding pairs—there is very little genetic variation left to work with. Low diversity means a limited genetic toolkit for adapting to a rapidly changing environment.

Researchers now describe the southern residents as dangerously close to the **extinction vortex**: the threshold beyond which the compounding effects of inbreeding, genetic drift, and poor reproductive success make recovery essential impossible. As one scientist studying them put it, with a population this small, there is a very thin margin between recovery and the point of no return.

Source: Harper, K. (2026). The Imperiled Orcas of the Salish Sea. *Scientific American,* 334(1), 22-33.

The Founder Effect

A related phenomenon occurs when a small group of individuals breaks away from a larger population and establishes a new one in a different location. This is called the **founder effect**. Since the founding group is small, it carries only a fraction of the genetic variation present in the original population. Alleles that were rare in the parent population may be common in the new one, and alleles that were common from the original (parent) population may be absent entirely.

The Old Order Amish of Lancaster County, Pennsylvania, provide a well-studied example. All approximately 50,000 current members trace their ancestry to roughly 80 individuals who emigrated from Switzerland in the mid-1700s to escape religious persecution. Because the Amish community has historically chosen mates from with the group, they have maintained a relatively closed gene pool descended from those original founders. Recessive traits that were rare in the broader Swiss population appear at much higher frequencies in Lancaster County Amish communities, including **Ellis-van Creveld syndrome**, a form of dwarfism rarely seen in the general population.

A similar dynamic shapes the distribution of the Tay-Sachs allele among Ashkenazi Jewish people whose ancestors lived in the Jewish communities of Eastern Europe. Ashkenazi Jews descend from a relatively small founding population that experienced a severe bottleneck during the persecutions and forced migrations of medieval Europe. The Tay-Sachs allele just happened to be

present at elevated frequencies from the very start. Like the Amish, the practice of **endogamy**—choosing mates from within a small, closed group based on religious affinity—unwittingly concentrated and maintained the Tay-Sachs allele across generations right up to the present day.

A striking visual example of the founder effect comes from the Similipal Tiger Reserve in the eastern Indian state of Odisha. About half of the reserve's roughly 30 tigers carry a rare mutation called **pseudo-melanism**, which causes their black stripe to widen dramatically until they dominate the coat, giving the animals a dark appearance quite unlike any other tiger population in the world (Yadav 2025).

For a period of time, a single male known as T12 was effectively the only breeding male in the reserve and he passed the trait to a large proportion of the next generation. With such a small, geographically isolated population cut off from other tiger habitats by human development, there was no influx of outside alleles to dilute the trait. The result is a population where a rare mutation has now become common, not through natural selection, but through chance.

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

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DDIndia (2023, December 22). *Similipal's black tigers. | Only 10 in India | DD India. [Video]*. YouTube. https://www.youtube.com/watch?v=XOtX_2NI4AM

Conservationists now worry that Similipal's tigers, like the southern resident orcas of the Salish Sea, illustrate the same dangerous scenario: when a population shrinks and closes in on itself, genetic diversity erodes, and the consequences show up in ways that range from reduced fertility to signs written right across an animal's coat.

The founder effect and population bottlenecks illustrate that evolution doesn't always move in a purposeful direction. Sometimes allele frequencies change simply because of who happened to survive, who happened to leave, or who happened to find a mate. Reduced genetic diversity in small populations also raises the risk of genetic diseases, because rare recessive alleles have a higher probability of being inherited from both parents.

Gene Flow: Alleles on the Move

The third force of evolution is traditionally called **gene flow**. When individuals move from one population to another and reproduce, they carry their alleles with them. This movement of alleles between populations is called gene flow, and can be a powerful force for spreading genetic variation across space.

Gene flow tends to reduce genetic differences between populations. When alleles flow freely between groups, those groups become more genetically similar over time. As you'll learn in the next chapter in more detail, this explains why it's not possible to group humans into any genetically distinct biological races. Across the vast majority of our DNA, you'll find **admixture**—the blending of genetic material from groups that were previously more separated. For the most part, there are not distinct or isolated human gene pools. Not only are all living humans part of the same species, we are all, genetically speaking, deeply interconnected.



Figure 5.2.7: Human admixture through gene flow has been happening throughout human history. Image produced by Google Gemini.

Gene Flow Between Species: Hybridization

When gene flow occurs between different subspecies or closely related species, it's called **hybridization**. One example of this involves the Africanized honeybee, or "killer bee," a hybrid of the African honeybee (*Apis mellifera scutellata)* and various European honeybee subspecies. All honeybees worldwide are classified as *Apis mellifera*, but due to adaptations to various environments around the world, there are around 30 different subspecies, the African honeybee being one of them.



Figure 5.2.8$a-b$: An example of hybridization. a) African honeybee (*Apis mellifera scutellata)* on the left and b) European honeybee *(Apis mellifera)* on the right. a) Image by: JMK, CC BY-SA 4.0 via Wikimedia Commons; b) Image by Sputniktilt, CC BY-SA 3.0 via Wikimedia Commons.

In the 1950s, a researcher in Brazil was attempting to breed a honeybee better suited to tropical climates by crossing African and European subspecies. In 1957, the project took an unexpected turn when a visiting beekeeper accidently released 26 African queen bees into the Brazilian countryside. Those queens ended up interbreeding with local European honeybees, producing hybrids that proved to be highly aggressive and dangerous. The hybridized bees spread rapidly through South America, reaching Mexico and California by 1985 and establishing colonies in Texas by 1990. By 1997, 90% of bee swarms trapped around Tucson, Arizona were hybrids. This example illustrates how quickly gene flow can alter a population's characteristics.

Natural Selection: Evolution with Direction

Of the four forces of evolution, natural selection is the one most people have heard of and it is the one that gives evolution its apparent direction. While mutation generates random variation and genetic drift changes allele frequencies by chance, natural selection is not random. As you learned in Chapter 3, it is driven by conditions in the environment. Natural selection can be classified as directional, balancing/stabilizing, or disruptive/diversifying depending on how the pressure is applied to the population.

Directional Selection

When the environment consistently favors one extreme of a trait over others, the result is **directional selection**. Allele frequencies shift steadily in one direction, generation after generation. A recent and still-unfolding example comes from the Africanized honeybee. As discussed in the gene flow section, this hybrid between African and European subspecies spread rapidly through the Americas. Its northward advance into the United States was at first slowed by cold winters since the African bee's tropical origins left it poorly suited to surviving prolonged cold. For a time, researchers believed the southern part of the country represented the limit to the hybrid's range.

However, climate change appears to be lifting that limitation. As winters across the southern and southwestern United States have grown milder, Africanized bees have continued pushing farther north than what researchers had predicted. More recent research confirms that over 60% of feral honey bee colonies in San Diego County are Africanized (Kohn, et al. 2015). The traits that make the African bee so successful in warm environments—efficient foraging in heat, rapid colony growth, strong defensive behavior—are being favored by natural selection as the climate shifts in their direction. Interestingly, genomic studies reveal that the adaptive advantage isn't a matter of one or two key genes, but a whole suite of climate-related traits being selected for simultaneously giving these more aggressive and dangerous hybrids an edge (Corbett-Detig, et al. 2020).

Balancing Selection

Balancing selection, also called **stabilizing selection**, occurs when intermediate versions of a trait are favored over the extremes. Human birth weight is a frequently cited example. Across human populations, average birth weight tends to cluster in a range that balances the need for babies to be small enough to avoid complications during birth but big enough to maintain a safe body temperature after they are born.

Sickle cell anemia, discussed earlier, provides another strong example. In populations where malaria is common, neither allele is simply "good" or "bad"—it all comes down to how many copies you carry. Two copies of the normal allele (*homozygous dominant*) means you have a high risk of malaria. Two copies of the sickle cell allele (*homozygous recessive*) produces sickle cell disease. Inheriting one copy of each allele (*heterozygous*) provides protection against malaria without the disease. Natural selection maintains both alleles in the population because the heterozygous genotype provides an advantage over either homozygous alternative, which is why the sickle cell allele has persisted in malaria-prone regions rather than being eliminated.

Disruptive Selection

Disruptive selection, also called **diversifying selection**, is the opposite of balancing selection. In this case, both extremes of a trait are advantaged while intermediate forms are at a disadvantage. Over time, this can split a population into two distinct groups. Darwin observed an example of this in the finches of the Galapagos Islands. Seed-eating finches tended to have either large, powerful beaks capable of cracking big seeds, or small, precise beaks suited for picking up tiny seeds. Plants on the islands offered few medium-sized seeds, so birds with intermediate beak sizes were less efficient at both tasks. Selection favored the extremes. Darwin proposed that this kind of divergent pressure, sustained over many generations, could gradually lead one populations to split into two separate species, called **speciation**.

Sexual Selection

Sexual selection is a particular form of natural selection in which the selective pressure operates through mate choice, sometimes at the risk of survival. Traits that make an individual more attractive to potential mates will spread in the population, even if those traits carry some survival cost. The peacock's elaborate tail is a classic example. It is metabolically expensive to grow, makes the bird more visible to predators, and yet it persists because peahens preferentially choose males with more

impressive displays.

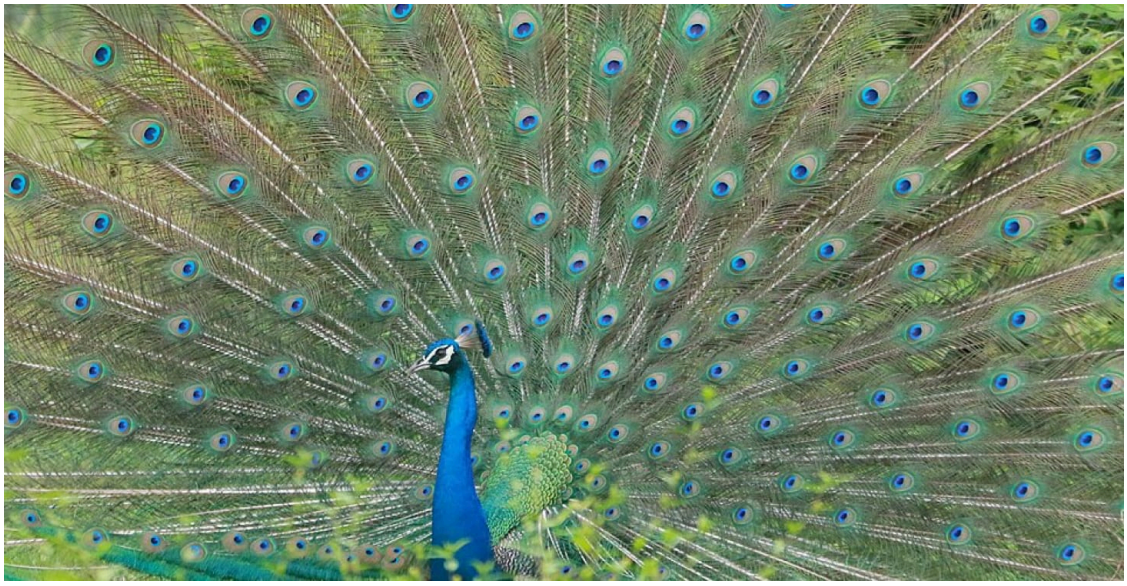


Figure 5.2.9: Peacock's striking tail display. Shino jacob koottanad, CC BY-SA 4.0 via Wikimedia Commons.

The túngara frog of Central America is another interesting example, revealing just how sharply natural selection and sexual selection can push against each other. Male túngara frogs produce two types of calls to attract females: a simple whine, and a more complex call that adds a series of short, low-frequency sounds called "chucks", to the whine. Females consistently prefer the more complex call, and males that produce it enjoy significantly greater reproductive success. Except for one problem: a frog-eating bat that hunts by homing in on frog calls. These bats are just as attracted to the complex whine-chuck call as female frogs are, and preferentially attack males producing it (Akre, et al. 2011).

This means that a male túngara frog faces a genuine dilemma every time he calls. The call most likely to attract females is also the call most likely to attract a predator. Research has shown that males will adjust their calling behavior depending on perceived predation risk. They will shift toward simpler calls when bats are active nearby. This case offers a fascinating look at sexual selection and natural selection operating simultaneously on the same trait yet pulling in opposite directions.

Did You Know?

Got Milk?: The Story of Lactose Tolerance in Humans



Figure 5.2.10: Milk in a glass bottle and a carton. Joseph Tylczak, CC BY-SA 3.0 via Wikimedia Commons.

The Puzzle

Most people assume lactose intolerance is the exception, but it's actually the rule. The majority of adults worldwide cannot comfortably digest lactose, the primary sugar found in milk. Lactose tolerance in adulthood is relatively rare globally, and is most common among people of Northern European descent.

As mammals, it makes sense that virtually all humans can digest lactose as infants. The digestive system of a newborn is equipped with an enzyme called **lactase**, which breaks lactose into simpler sugars that can be absorbed. But in most people, the gene that produces lactase is gradually switched off after weaning. So what happened in populations with high rates of adult lactose tolerance? The answer involves every force of evolution discussed in this chapter.



Figure 5.2.11: A father of Middle Eastern descent feeds his baby milk from a bottle. Image produced by Google Gemini.

Mutation Creates the Possibility

The starting point, of course, is a mutation. In most humans, the lactase gene carries a regulatory switch that turns off after childhood. But in some individuals, a mutation in that regulatory regions keeps the gene active throughout adulthood. Like all mutations, this one arose randomly. In fact, it arose separately in multiple populations. Europeans carry one version, several African populations carry different versions, but they all have the same outcome: **lactase persistence**.



Figure 5.2.12: A woman of Scandinavian descent enjoying a glass of milk. Image produced by Google Gemini.

Natural Selection Spreads the Mutation

A mutation that arises by chance will only spread if it provides some advantage in the environment. For most of human history, adult lactose tolerance wouldn't have provided a particular benefit since most human societies didn't have access to fresh milk from domesticated animals. That changed with the domestication of cattle and other dairy producing animals, which appears to have begun in the Middle East and parts of Africa roughly 9,000 years ago. Once humans had herds of cows, goats, or sheep producing milk, the ability to consume that milk directly became a genuine advantage. Milk provided calories, protein, and crucially, during droughts, a source of hydration. In populations that depended on dairying, individuals who could digest milk as adults were more likely to survive and reproduce. Natural selection favored the lactase persistence mutation. Its frequency increased steadily through **pastoralist** based populations.



Figure 5.2.13: Maasai pastoralist from with his cattle. Image by Rasheedhrasheed, CC BY-SA 4.0 via Wikimedia Commons.

Gene Flow and Genetic Drift Shape the Distribution

As dairying cultures migrated and interacted with neighboring populations, gene flow spread the lactase persistence gene further. Populations that had not been dairying but came into contact with those that were would have received the allele through interbreeding. The current global distribution of lactose tolerance—high in Northern Europe and some East African and Middle Eastern populations, low elsewhere—reflects the historical geography of cattle domestication and the subsequent movement of people.

Genetic drift also played a role. In small, isolated dairying populations, chance fluctuations could have helped or hindered the spread of the mutation, independent of its adaptive value. The interplay of all four forces shaped the outcome we see today.

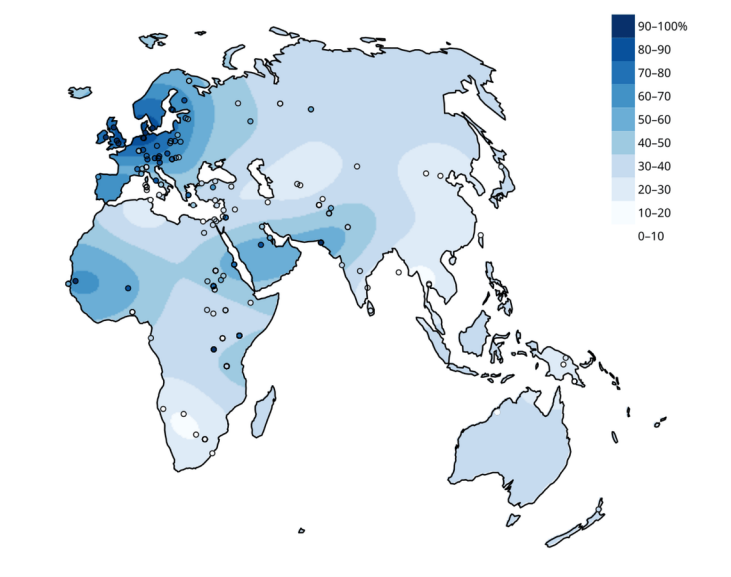


Figure 5.2.14: Map of the percentage of adults that can digest lactose in the indigenous population of the Old World. Circles mark sample locations. Image by: Joe Roe, CC BY 4.0 via Wikimedia Commons.

The Bigger Picture

The lactose tolerance story carries an important lesson: human culture and human biology do not evolve independently. The way we live shapes the selective environment in which our genes our tested. The shift to dairying introduced a new condition that acted upon the mutation sitting in the genome. This kind of gene-culture co-evolution, in which cultural practices and genetic evolution influence one another is one of the defining features of human evolutionary history.

Source: *Got Lactase?* (2007). UC Museum of Paleontology Understanding Evolution, www.understandingevolution.org.

Why the Forces of Evolution Matter Today

In today's modern world, understanding these evolutionary processes is crucial for developing immunizations and antibiotics that can keep up with the rapid mutation rate of viruses and bacteria. This is also relevant to our food supply, which relies in large part on the development of herbicides and pesticides that keep up with rapidly evolving pests and weeds. Viruses, bacteria, agricultural pests, and weeds have all shown great flexibility in adapting to the tools we use to combat them. Billion-dollar industries have specialized in trying to keep our species one step ahead of the next mutation in the pests and infectious diseases that put our food supply and health at risk.

Even gene-editing technologies like CRISPR-Cas9, which allow scientists to alter DNA with remarkable precision, do not change the fundamental rules. The genome remains capable of generating random mutations, and those mutations will continue to be subject to drift, flow and selection. Knowing the forces of evolution gives us the conceptual tools to understand both the possibilities and the limits of genetic intervention.

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5.3: Key Terms

Key Terms

Admixture – A term often used to describe gene flow between human populations. Sometimes also used to describe gene flow between nonhuman populations.

Allele frequencies - The ratio, or percentage, of one allele compared to the other alleles for that gene within the study population**.**

Alleles – variant forms of genes.

Balancing (stabilizing) selection – a pattern of natural selection that occurs when the extremes of a trait are selected against, favoring the intermediate phenotype (also called stabilizing selection).

Codons – Three-nucleotide units of DNA that function as three-letter "words," encoding instructions for the addition of one amino acid to a protein or indicating that the protein is complete**.**

Directional selection – A pattern of natural selection in which one phenotype is favored over the other, causing the frequencies of the associated advantageous alleles to gradually increase.

Disruptive (diversifying) selection – a pattern of natural selection that occurs when both extremes of a trait are advantageous and intermediate phenotypes are selected against (also known as diversifying selection).

Ecotypes – a genetically distinct population within a single species that has adapted to specific environmental condition.

Ellis-van Creveld syndrome – An autosomal recessive disorder characterized by short stature (dwarfism), polydactyly (the development of more than five digits [fingers or toes] on the hands or feet), abnormal tooth development, and heart defects. Estimated to affect approximately one in 60,000 individuals worldwide, among the Old Order Amish of Lancaster County, the rate is estimated to be as high as one in every 200 births.

Endogamy – refers to the cultural, social, or legal practice of marrying only within the limits of one's own local, religious, ethnic, or social group to preserve cultural traditions, religious beliefs, or socioeconomic status.

Extinction vortex – refers to a downward demographic and genetic spiral that small, isolated populations enter. Once a population drops below a critical threshold, factors like inbreeding, random genetic drift, and environmental fluctuations reinforce one another, accelerating the population's decline until it inevitably spirals into extinction.

Gametes – the reproductive cells (eggs and sperm), produced through meosis.

Gene flow – the movement of alleles from one population to another.

Gene pool – the entire collection of genetic material in a breeding community that can be passed on from one generation to the next.

Genetic drift – random changes in allele frequencies within a population from one generation to the next.

Genotype – the set of alleles that an individual has for a given gene.

Heterozygous genotype – a genotype consisting of two different alleles.

Homozygous genotype – a genotype consisting of the same alleles.

Hybridization – a term often used to describe gene flow between non-human populations.

Inherited mutation – a mutation that has been passed from parent to offspring.

Lactase – an enzyme that breaks down lactose into simpler, easily absorbed sugars

Lactase persistence – the ability to continuously produce the enzyme lactase throughout adulthood, allowing individuals to digest lactose, the sugar in milk.

Last Universal Common Ancestor (LUCA) – the ancient organism from which all living things on Earth are descended.

Malaria – a frequently deadly mosquito-borne disease caused by infection of the blood by a *Plasmodium* parasite.

Modern Synthesis – the integration of Darwin's, Mendel's, and subsequent research into a unified theory of evolution.

Mutation – a change in the nucleotide sequence of the genetic code.

Origins of life – how the first living organism came into being.

Pastoralist – someone who raises and manages domesticated livestock.

Phylogenetic tree of life – a family tree of all living organisms, based on genetic relationships.

Phylogenies – genetically determined family lineages.

Population – a group of individuals who are genetically similar enough and geographically near enough to one another that they can breed and produce new generations of individuals.

Population bottleneck – a type of genetic drift that occurs when the number of individuals in a population drops dramatically due to some random event.

Pseudo-melanism – a genetic variation where an animal has unusually dark, enlarged or merged stripes and spots (also called abundism).

Sexual selection – an aspect of natural selection in which the selective pressure specifically affects reproductive success (the ability to successfully breed and raise offspring).

Sickle cell anemia – an inherited blood disorder cause by a genetic mutation affecting hemoglobin, causing blood cells to become rigid and crescent shaped which block blood flow and cause severe pain crises, anemia, and organ damage.

Somatic cells – the cells of our organs and other body tissues (all cells except gametes) that replicate by mitosis.

Speciation – the process by which a single population divides into two or more separate species.

Spontaneous mutation – a mutation that occurs due to random chance or unintentional exposure to mutagens.

Tay-Sachs disease – a fatal genetic disorder caused by a mutation in the HEXA gene that lead to a buildup of harmful fatty substances that damages the nervous system.

Viable offspring – offspring that are healthy enough to survive to adulthood.

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5.4: References and Attributions

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6: HUMAN VARIATION

Learning Objectives

- Assess the troubling history of "race" concepts and how they developed.
- Explain human variation and evolution as the thematic roots of biological anthropology as a discipline.
- Evaluate older ideas about biological "race" using what we know about human genetic variation.
- Describe how human genetic variation is distributed gradually across geography, and explain how patterns of migration are connected to that distribution.
- Identify phenotypic traits that reflect selective versus neutral evolution.
- Consider a more nuanced view of human variation for today's research including the implications for biomedical studies, applications in forensic anthropology, and other social, cultural, and political concerns.

6.1: A Brief and Troubling History of Race Concepts

6.2: What the Genetics Actually Shows

6.3: Clinal Variation

6.4: Race as a Social Construct

6.5: Race, Ancestry, and Ethnicity

6.6: Medicine, Forensics, and Social Justice

6.7: Key Takeaways

6.8: Key Terms

6.9: References and Attributions

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6.1: A Brief and Troubling History of Race Concepts

The concept of race as we know it today did not stem from neutral scientific inquiry. It was shaped by the social and political contexts of **colonialism**, slavery, and European expansion and was often used to justify the exploitation of people deemed inferior by those in power (Goodman 2020).

Early Classification Systems

Carl Linnaeus, who developed the first formal system of biological classification in 1735, sorted humans into separate "subspecies" based on geography and appearance. But he didn't stop there: he also assigned each group supposed mental and moral characteristics, descriptions that were sweeping stereotypes based on Euro-centric ideals rather than scientific observations. These early classifications planted seeds that would grow into something deeply harmful.

Phrenology—the pseudoscientific practice of inferring personality and intelligence from skull shape—gained popularity in the 18th and 19th centuries. Phrenologists and like-minded researchers, including Samuel Morton (whose skull collection became a landmark case of data manipulated to fit racial assumptions), claimed that skull measurements could rank human groups by intelligence and moral character. Their findings, unsurprisingly, always confirmed the supremacy of Europeans. This wasn't science, it was cloaking prejudice in the language of science.

Scientific Racism and Social Darwinism

As evolutionary theory gained traction in the 19th century, some thinkers twisted Darwin's ideas into a framework called **Social Darwinism**. They argued that some "races" were more evolutionarily advanced than others, and that European colonization was therefore natural or even beneficial. This was a profound misapplication of evolutionary science. Darwin never claimed that human groups represented different stages of evolution, and the evidence then, as now, has never supported such a view.

These ideas have had devastating real-world consequences. They were used to justify the transatlantic slave trade, colonial conquest, forced removal of Indigenous peoples, and laws barring interracial marriage. In the early 20th century, **eugenics** emerged as a particularly horrifying application. This was the idea that society could be "improved" by preventing certain people from reproducing. Indiana passed the first eugenics sterilization law in 1907. California followed in 1909 and would go on to carry out nearly half of all forced sterilizations in the country. Up until 1970, more than 30 U.S. states had similar laws targeting people labeled as criminals, people with disabilities, and others deemed "unsuitable" by those in power.

The Anthropological Reckoning

Not everyone went along with these ideas. Franz Boas, one of the founders of modern anthropology, conducted careful studies of head shapes among immigrant families in the early 20th century. He found that environmental factors such as diet, economic conditions, and upbringing affected skull shape far more than heredity or "race." Boas argued that race was not a fixed biological category, but it took decades for the broader scientific community to catch up. The American Anthropological Association did not formally reject race as a valid biological category until 1998.

By World War II, as the horrors of Nazi racial ideology became undeniable, anthropologists began to openly reckon with the ways their own discipline had contributed to racist frameworks. In the decades since, major professional organizations like the American Anthropological Association have issued formal statements rejecting race as a valid biological category. The field has worked to dismantle the legacy of scientific racism, and that work is still ongoing.

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6.2: What the Genetics Actually Shows

What does the science say about human genetic variation? The picture is both surprising and clarifying.

We Are Remarkably Similar

One of the major revelations of modern genetics is just how genetically similar all humans are. Across the entire human species, we share approximately 99.9% of our DNA. The remaining 0.1% accounts for all of the genetic differences between every person on Earth including all the variation in appearance, health risks, and ancestry. In comparison to other primates and mammals, humans show very little genetic diversity. Why? Because we are a relatively young species.

Modern *Homo sapiens* first appeared roughly 300,000 years ago, with populations spreading widely only about 100,000 years ago. In evolutionary terms, this is not very long. Our populations have simply not been isolated from one another long enough to develop into any genetically distinct subspecies, which is precisely what distinct biological races would require.

Variation Lives Within Groups, Not Between Them

Here is a finding that surprises many people: the vast majority of human genetic variation exists *within* populations, not between them.

In a landmark 2002 study, Noah Rosenberg and colleagues analyzed 377 variable genetic markers across 1,056 individuals from 52 populations worldwide. What they found was that 93-95% of all human genetic variation occurs within populations while only 3-5% of variation can be attributed to differences between major groups. In other words, any two people from the same "race" may be more genetically different from each other than from someone of a completely different "race" (Rosenberg et al. 2002).

This doesn't mean there are zero differences between populations—there are—but those differences are small, gradual, and do not correspond to the discrete racial categories humans have constructed.



Figure 6.2.1: World map painted on human hands. Image by stokpic from Pixabay.

Africa: The Most Genetically Diverse Place on Earth

Another fascinating find is that there is more genetic diversity among people of African ancestry than among all other human populations combined. This makes perfect sense when you understand human evolutionary history. Our species originated in

Africa and spent most of its history there. Only smaller subgroups migrated out of Africa relatively recently, carrying with them a subset of the genetic diversity that existed on the continent. As populations moved further from Africa, they experienced **founder effects** and **genetic drift** that reduced their diversity even further. This is why genetic variation decreases the further a population is from sub-Saharan Africa.

This pattern directly undermines old racial hierarchies, which often placed Africans at the “bottom” of human hierarchies. In reality, African populations contain the deepest and richest genetic diversity of our species.

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6.3: Clinal Variation

Why Traits Don't Draw Clean Lines

If human populations don't divide into discrete races, how does biological variation actually distribute itself? The answer is through what scientists call **clinal variation**. Clinal variation means that a trait changes gradually across geographic space, rather than jumping abruptly from one category to another.

Skin Color: A Case Study in Clinal Traits

Skin color is the most commonly used phenotype to sort people into racial categories, yet it is actually one of the clearest examples of why racial categories fail.

Skin pigmentation is primarily determined by the amount of **melanin** the body produces. Darker skin evolved as protection from intense ultraviolet radiation near the equator where UV exposure is high and can damage DNA and deplete folate—a nutrient critical for fetal development. Lighter skin evolved at higher latitudes where UV exposure is lower and where the body needs more UV light to synthesize vitamin D. So skin color reflects a very specific adaptation to UV radiation, and little else (HHMI Biointeractive; Jablonski 2004; Jablonski and Chaplin, 2000; Lee 2015; Long and Kittles, 2003).

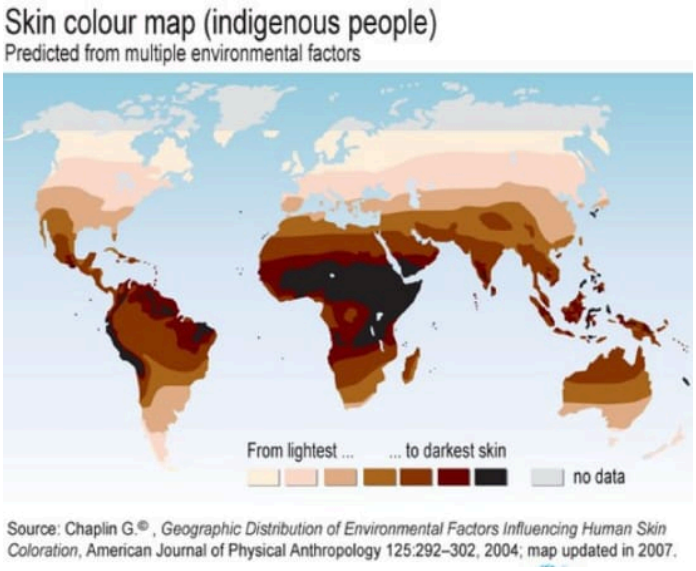


Figure 6.3.1: Clinal variation in indigenous human skin tone as distributed geographically. Map produced by Chaplin, G. (2007). Sourced from Flickr.

A 2002 study found that about 88% of global skin color variation can be attributed to genetic differences between populations, which may sound like it might support racial categories. However, there's a crucial point: that distribution does not align with other genetic markers. Most genetic variation is found *within* populations, while skin color varies *between* them (Relethford 2009). Skin color is atypical, shaped by strong and specific selective pressure. It cannot tell you anything reliable about a person's ancestry, personality, intelligence, or health, and it certainly cannot define a race.

People from very different parts of the world can have nearly identical skin tones through independent evolution. Many different, unrelated groups independently evolved darker or lighter skin based on their environments. Skin color is not a window into deeper genetic identity. It's an adaptation to sunlight.

Other Traits: Blood Type, Lactase Persistence and More

Skin color is not the only trait that varies clinally. Other traits you've learned about earlier also follow this pattern. ABO blood type frequencies shift gradually across populations, with no clean breaks between groups. Lactase persistence, the ability to digest milk sugar (lactose) into adulthood, evolved independently in several pastoral societies, including those in Europe, East Africa, and the Middle East, where animal herding created selective pressure for this trait. What these traits share is that each evolved in response to a specific environmental or cultural pressure. They vary geographically, but not in ways that map onto racial categories. That's because they are **non-concordant**: a person with light skin might have Type B blood, low lactase persistence, and thick, curly hair. No combination of traits reliably clusters into discrete racial groups.



Figure 6.3.2: Most human biological traits are non-concordant, meaning traits vary independently and each trait has its own pattern of distribution around the world. In this image, different colors and patterns represent trait varieties. For example, the color and pattern of the head may represent hair color (dark to light), but sharing dark hair with another person does not mean you will share other traits (e.g. ability to digest lactose or ABO blood type). Credit: Nonconcordance original to Explorations: An Open Invitation to Biological Anthropology (2nd ed.) by Katie Nelson is under a CC BY-NC 4.0 License.

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6.4: Race as a Social Construct

The Very Real Consequences

If race has no solid biological foundation, why does it still matter so much? Because while race may not be biologically "real," it is socially very real, and the consequences of racial classification have been, and continue to be, profound.

Race is Invented, Not Discovered

Race is best understood as a **sociohistorical construct**. That is, a set of categories that societies create and maintain for social, political, and economic reasons (Fuentes, et al., 2019). These categories shift over time and vary from place to place. What counts as "Black" in Brazil is not the same as what counts as "Black" in the United States. Irish and Italian immigrants were once not considered fully "white" in America. If race were a biological fact, it would look the same everywhere—but it doesn't.

The racial categories most Americans recognize today were largely invented in the 19th century, in the context of slavery and colonial expansion. They were designed to justify systems of inequality, not to describe biological reality. As anthropologist and former American Anthropological Association president Yolanda Moses explains, three common misconceptions drive our understanding of race: that humans divide neatly into a small number of distinct races; that those races differ in inherent intelligence or character; and that racial differences are fixed in our biology. Modern genetic research has dismantled all three.

Hypodescent and Anti-Miscegenation Laws

Hypodescent practices are used to enforce social hierarchies, ensuring that minority groups remain minorities. One of the most well-known examples of hypodescent is President Barrack Obama, the 44th president of the United States. Largely considered the first Black president, Obama has one Black and one white parent. Because of hypodescent, where people of "mixed races" are automatically assigned to the minority race of their parents, Obama is considered Black instead of white or mixed. This is purely for social reasons. This strict definition of who can be recognized as the dominant race increases the selectivity and status of the dominant group, making it more difficult to be a member.



Figure 6.4.1: President Barack Obama at a Democratic Rally in October 22, 2010 (cropped). Image credit: Neon Tommy, CC BY-SA 2.0 via Wikimedia Commons.

Other historic legislation enforced social and racial separation between people. For example, prior to the Civil War, in Maryland, a white woman married to an enslaved Black individual was considered the owner of her husband and his parents. Any offspring

from their union were also born into slavery. Although the particulars of these laws changed over time, many states continued to ban "mixed" marriages well into the 20th century. In 1967, the Supreme Court decision on *Loving v. Virginia* resulted in all remaining **anti-miscegenation laws** being repealed in the U.S., but at that time, 16 U.S. states still had anti-miscegenation laws. Until future-president Barrack Obama was six-years-old, his parents' marriage was considered illegal in many U.S. states.

Colorblindness vs. Color Consciousness

When confronted with the evidence that race isn't biologically real, a common response is: "So shouldn't we all just be **colorblind**?" While this may be a well-intentioned idea, scholars argue it's actually counterproductive. Declaring that race doesn't exist, or that we should simply stop paying attention to it, makes it harder to identify and address the very real racial inequalities that persist in our society. Pretending not to see human variation doesn't make **racism** disappear—it just makes it harder to name and confront (Wise 2010).

Implicit Bias and Microaggressions

Implicit biases are mental shortcuts and associations we carry, often without being aware of them. They are absorbed from childhood through observation, media, interactions, and culture. Research has consistently shown that implicit biases reinforce racial, gender, disability, and other social stereotypes, affecting everything from hiring decisions to medical treatment.

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

Freedom Project Wa (2019, April 12). *Implicit Bias: Peanut Butter, Jelly, and Racism.* [Video]. YouTube. https://www.youtube.com/watch?v=1JVN2qWSJF4&t=145s

Microaggressions are subtle comments or behaviors that, intentionally or not, perpetuate inequality in society by communicating demeaning messages to members of marginalized groups. For example, a patient in a hospital assumes that the women in scrubs are nurses and men in scrubs are doctors, or a patient assumes their doctor is foreign based on their appearance or accent, or the doctor assumes differences in pain perception based on the patient's skin color. In each of these situations, an individual makes what they consider a harmless or factual observation, but the implications, assumptions, and stereotypes strengthen inaccurate and demeaning labels. Over time, microaggressions add up and take a real toll on the people who experience them.

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6.5: Race, Ancestry, and Ethnicity

Getting the Terms Right

Part of what makes conversations about race so complicated is that we often conflate terms that mean very different things. Terms such as **race** and **ethnicity** are used in everyday conversations and in formal settings within and outside academia. The division of humankind into smaller, discrete categories is a regular occurrence in day-to-day life.

For instance, despite the Census Bureau's attempts for a more inclusive and expansive categorization of race, the concept is still fraught with controversy and poorly defined. As of 2020, people are free to explain their designated racial characterization in more detail, and the Census Bureau recommends that individuals describe their ethnicity as well. However, people remain limited to a set of predetermined options that are not consistently defined. For example, "White" is defined as anyone identifying with "one or more nationalities or ethnic groups originating in Europe, the Middle East, or North Africa," while "Black or African American" is defined as anyone identifying with "one or more nationalities or ethnic groups originating in any of the Black racial groups of Africa."

Note that skin color and race are not underscored in the "White" definition, and only in the "Black" definition. "American Indian or Alaska Natives" must "maintain tribal affiliation or community attachment," and so this definition potentially excludes disenfranchised or unrecognized populations, regardless of how they identify, while "Asian" groups are partially subdivided by ethnicity based on political concerns today. Chinese and Vietnamese are among several groups identified as "Asian" subgroups, while others, such as Pakistani, Hmong, and Cambodians, are grouped together as "Other Asians." These inconsistent definitions and cherry-picking of heritages highlight the persistent political nature of the race (and ethnicity) question in the U.S. and the inefficacy of racial categories.

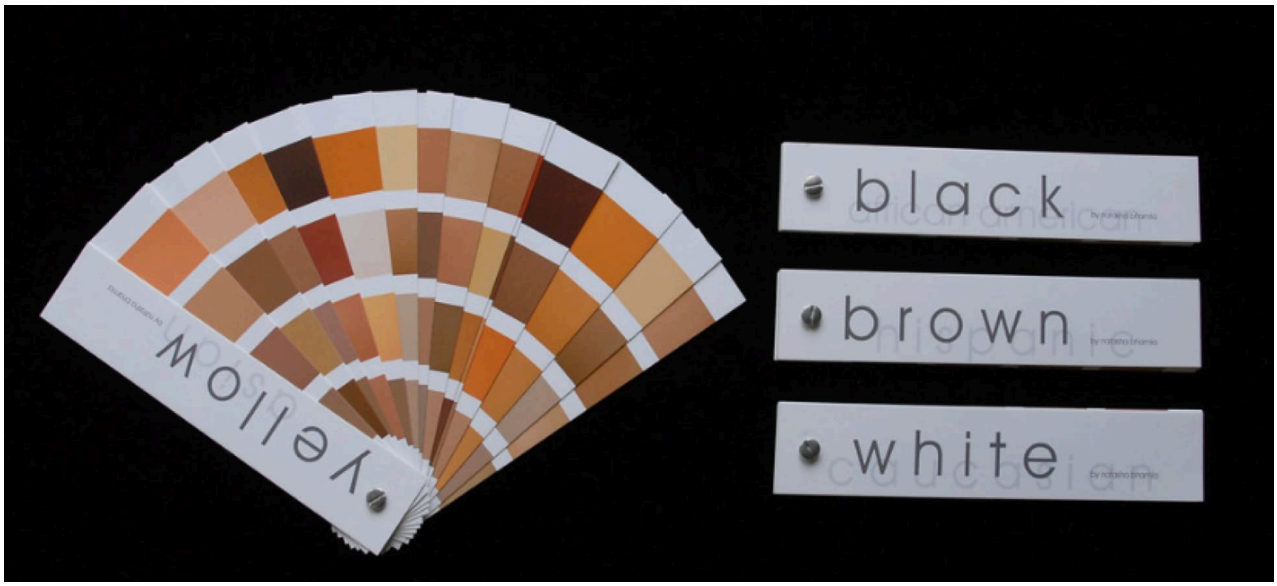


Figure 6.5.1: Four books of color swatches grouped by "yellow/asian", "black/african-american," "brown/hispanic," and "white/caucasian." The "yellow/asian" book is opened to reveal a fan of many skin tone colors. Each color swatch was taken from a macro photograph of a person from this racial category. This project called "Skin Swatches" (2008) is by Natasha Bhamla. Image sourced from Flickr.

Biological anthropologists distinguish carefully between race, ancestry, and ethnicity.

Ancestry refers to the geographic and genetic origins of one's biological lineage, meaning, where your forebears lived and the genetic adaptations they developed in response to their environments. Ancestry is both real and scientifically meaningful. It can tell us about disease risks, adaptations to altitude or climate, and migration history. All humans have ancestry and none is superior or inferior to any other.

Ethnicity refers to a shared cultural identity deriving from a sense of belonging based on language, religion, customs, history and

traditions. Ethnicity is primarily a social and cultural concept, not a biological one. People can share an ethnicity without being closely related genetically.

Race, as we have seen, is a socially constructed category that different societies define differently, and that has no consistent biological basis. The key distinction is that while ancestry is, to an extent, biologically meaningful, race is not.

Anthropologists commonly group ancestral variation by continent—European, African, Asian, Indigenous American—but these are rough and overlapping clusters, not sharp divisions. In an increasingly globalized world where people migrate, intermingle, and form families across every imaginable background, these categories become harder to apply.

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6.6: Medicine, Forensics, and Social Justice

Race and Medicine

Medicine has long used race as a variable in diagnosis and treatment, but this practice is complicated. As you've learned in previous chapters, some health conditions do cluster in specific populations. For example, sickle cell anemia is more common among people with ancestry from sub-Saharan Africa, the Mediterranean, and parts of India, because the sickle cell trait offers some protection against malaria for people living in those regions. Tay-Sachs disease is more common among Ashkenazi Jewish populations. These patterns reflect ancestry, not race.

The danger comes when race is treated as a biological category that predicts health outcomes beyond these specific cases. Research has shown that assumptions based on race, such as differences in pain perception and tolerance between Black and white patients, are simply false, yet they persist in medical training and practice and have measurable consequences for patient outcomes.



Figure 6.6.1: Doctor and patient reviewing medical chart together. Image produced by Google Gemini.

Forensic Anthropology

In forensic contexts, biological anthropologists help identify human remains by analyzing skeletal features associated with biological sex, age, stature, and geographic ancestry. The latter might sometimes be referred to as "race" in forensic contexts, but forensic anthropologists are careful to emphasize that they are estimating geographic ancestry from skeletal morphology, not assigning someone to a social racial category.

Forensic ancestry estimation uses statistical patterns in skeletal traits that vary gradually across populations, much like the clinal variation discussed earlier. It is a probabilistic tool that requires multiple data points. However, it also bears mention that rates of incarceration and wrongful conviction, historically and presently, are skewed along racial lines. **The Innocence Project** is a nonprofit organization committed to exonerating wrongful convictions. Since 1992, they have helped overturn more than 200 wrongful incarcerations, and among these cases, they have documented the disproportionate impact of wrongful convictions on Black people in the United States (58% of cases as of December 2021). These perspectives, laws, and organizations highlight how racist ideas have perpetuated to the present day and still have significant impacts on people's rights and lived experiences in the U.S.

In this short video, forensic anthropologist Dr. Allysha Winburn describes the contention surrounding race and ancestry in her casework.

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

IUP Anthropology. (2020, October 27). *IUP Anthropology OER – Dr. Allysha Winburn: Forensic Anthropology and Race*. [Video]. YouTube. https://www.youtube.com/watch?v=ZRqsJHbiC_E

Racial Justice and Anthropology's Role

Social activist movements, from the civil rights movement to Black Lives Matter, have raised awareness of how racial inequalities continue to shape life and death in the United States and around the world. Biological anthropologists have both a scientific and a moral stake in these conversations. Our research can demonstrate, with precision and evidence, why the biological foundations of racism are false. It is also our responsibility to recognize that debunking biological racism is not enough. Correcting the science is the starting point, not the finish line, and dismantling the social structures built on false premises is work that belongs to all of us.



Figure 6.6.2: Students march for Black Lives Matter on May Day, 2015. Image by: Fibonacci Blue from Minnesota, USA, CC BY 2.0 via Wikimedia Commons.



Figure 6.6.3: Standing with Standing Rock in San Francisco. Image by Pax Ahimsa Gethen, CC BY-SA 4.0 via Wikimedia Commons.



Figure 6.6.4: WorldPride Madrid Summit on How to Make the LGBTQIA+ Community Inclusive Regardless of Class, Ethnicity, and Disability. Image by Earlyspatz, CC BY-SA 4.0 via Wikimedia Commons.

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6.7: Key Takeaways

One Human Family, One Common Home

Before we close, it's worth stepping back to ask: why does any of this matter? We have known for decades that biological race is not real. Human variation is gradual, continuous, and far more complex than any racial category can capture. And yet, racial thinking persists. It's embedded in our institutions, our assumptions, and our daily interactions. The gap between what the science shows and how society behaves is exactly why this chapter matters.

Let's bring the key points of this chapter together. The science of human variation leads us to the following conclusions:

- **Humans share approximately 99.9% of their DNA**. The 0.1% that differs accounts for all observed human variation.
- **Most genetic variation occurs within populations, not between them**. Studies consistently show that 93-95% of human genetic variation is found within groups, not between them.
- **Genetic diversity is highest in Africa**. Because our species originated there and has had more time to accumulate variation.
- **Many traits vary clinally—gradually across geography**. Skin color, blood type, and many other traits change gradually rather than in discrete jumps.
- **Skin color reflects adaptation to UV radiation and nothing more.** It cannot reliably predict other genetic or behavioral traits.
- **Race is a social construct, not a biological reality.** Racial categories are human conventions, vary by society, and change over time.
- **Race has real social consequences.** Even though race is not biologically real, racial classification shapes people's lived experiences, health outcomes, legal treatment, and economic opportunities.
- **Anthropologists have an obligation to engage.** We must use our scientific findings to combat misinformation about race and support efforts to achieve racial justice.

Studying human variation is more than an academic exercise. It is a lens through which we can better understand our shared evolutionary history, challenge harmful myths, and work toward a more accurate and equitable understanding of what it means to be human. We are, in the most profound biological sense, one species—varied, interconnected, and deeply alike.



Figure 6.7.1: Humanity Requires Human Kindness: One Human Family, One Common Home. Canva design by Rachel Mitchell

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6.8: Key Terms

Key Terms

Ancestry – Biogeographical information about an individual, traced either through the study of an individual's genome, skeletal characteristics, or some other form of forensic/archaeological evidence.

Anti-miscegenation laws – historical state statutes that criminalized interracial marriage and intimate relations.

Clinal Variation – Gradual changes in traits and inherited characteristics amongst groups and species that correlate with defined geographical or ecological spaces.

Colonialism – The historical practice of more powerful countries claiming possession of less powerful ones through full or partial political control, occupation, and economic exploitation.

Colorblind – A racial ideology that believes that society should not see racial group membership and race-based differences in order to end discrimination and bring about racial harmony.

Color conscious – A racial ideology that believes society needs to be aware of and actively acknowledging race in order to celebrate ethnic differences and recognize social justice issues.

Ethnicity – Self-determined cultural differentiations among populations, usually based upon attributes such as language, religion, lifestyle, cultural heritage, and/or nationality or geographic territory.

Eugenics – a set of beliefs and practices that involves the controlled selective breeding of human populations with the hope of improving their heritable qualities, especially through surgical procedures like sterilization and legal rulings that affect marriage rights for interracial couples.

Founder effect – a reduction in genetic variation that results when a small subset of a large population is used to establish a new colony.

Genetic drift – a change in allele frequency due purely to random chance.

Homogeneity – the quality of being genetically uniform.

Human variation – the biological differences observed among individuals and populations, including genetics, physiology, and outward appearance.

Implicit bias – Mental shortcuts that we may not be consciously aware of, such as stereotypes or attitudes, that can affect our perceptions, understandings, and even actions.

Innocence Project – A nonprofit, national litigation and public policy organization committed to exonerating wrongfully convicted people using DNA testing. They also seek to reform the criminal justice system to prevent future injustices from taking place.

Melanin – a natural pigment that determines the color your skin, hair, and eyes.

Microaggression – A statement, action, or incident regarded as an instance of indirect, subtle, intentional, or unintentional discrimination against members of a marginalized group such as a racial or ethnic minority.

Non-concordant traits – the fact of genes or traits not varying with one another and instead being inherited independently.

Phrenology – A pseudoscience primarily focused on measurements of the human skull as a supposed indication of mental abilities and character traits.

Prejudice – an unjustified attitude toward an individual or group that is not based on reason, whether positive (and showing preference for one group of people over another) or negative (and resulting in harm or injury to others).

Race – a socially constructed system that organizes people into hierarchical groups based on specific physical traits that are thought to reflect fundamental and innate differences that are rooted in genetic and biological differences.

Racism – any action or belief that discriminates against someone based on perceived differences in race or ethnicity.

Scientific racism – the pseudoscientific belief that empirical evidence exists to justify or support racism.

Social Darwinism – the now largely discredited theory that was common in the late 19th and early 20th centuries that stated that individuals, groups, and peoples are subject to the same Darwinian laws of natural selection as plants and animals. It was used to justify political conservatism, imperialism, and racism, and to discourage intervention and reform.

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6.9: References and Attributions

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7: INTRODUCTION TO PRIMATES

7.1: Traits of Primates

7.1.1: Eyes and Hands

7.1.2: Teeth and Diet

7.1.3: Locomotion

7.1.4: Brains, Development, Behavior

7.1.5: Habitat and Threats

7.2: Learning from Primates

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7.4: References and Attributions

Learning Objectives

- Explain how primates are different from other mammals.
- Identify different types of traits that are used to evaluate primate groups (taxa).
- Understand how studying non-human primates is important in biological anthropology.

The Rise of the Mammals

For most of their early history, mammals were not the dominant animals on Earth. For roughly 150 million years, our distant ancestors scrambled through the undergrowth as small, mostly nocturnal insect-eaters, living in the shadow of the dinosaurs. During this time, they were quietly accumulating traits that would set the stage for their world domination: warm blood and fur to stay active in the cold and dark, complex teeth for processing a wide range of foods, and most importantly, enlarged brains with sharper senses of smell, hearing, and touch. Mostly, they were just trying to eke out a living.



Figure 7.1:Reconstruction of a Jurassic mammal based on fossil evidence. Graphic image produced by Google Gemini.

Then, 66 million years ago, everything changed. An asteroid impact triggered a mass extinction that wiped out the non-avian dinosaurs, and with them, the ecological pressure that had kept mammals small and on the margins. The result was one of the most dramatic evolutionary radiations in the history of life. With so many environmental niches suddenly available, placental

mammals diversified into a wide array of species. Within a just a few million years—which in geological terms is almost overnight—the mammal family tree branched into the ancestors of nearly every major group alive today: rodents, hoofed animals, bats, carnivores, whales, and others.

One of those branches would pave the way for our own lineage to evolve: the primates.

Among the earliest post-extinction mammals discovered in the fossil record is a small, tree-dwelling creature with long grasping fingers and toes that lived roughly 63 million years ago. This tiny, unassuming mammal represents the beginning of not just our mammalian story, but our primate, and human evolutionary story as well.

Did You Know?

The Science of Mammalian Milk: You are What Your Microbes Eat

Here's a rather humbling fact: you couldn't digest your breakfast this morning without the help of trillions of microorganisms living in your gut. Humans and their gut bacteria have been coevolving for millions of years, and that partnership starts from the very first moments of life.

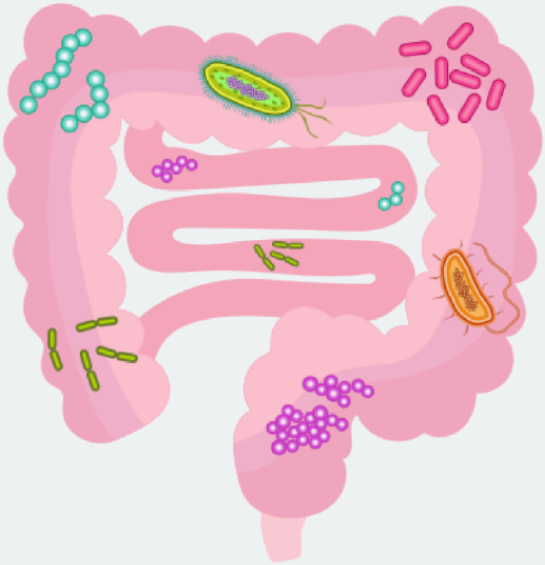


Figure 7.2: Gut microbiota. Image credit: DataBase Center for Life Science (DBCLS), CC BY 4.0 via Wikimedia Commons.

Before a newborn can extract any energy from food, it first needs to populate its intestines with the right bacterial tenants. This community of microorganisms—your microbiome—is uniquely yours, and its construction begins at birth. As a baby passes through the birth canal, takes in its mother's milk, and makes skin-to-skin contact with her, friendly bacteria rapidly colonize its intestines, laying the foundation for a lifetime of digestion, immunity, and overall health.

Mother's Milk: Not Just for Babies

Research from the last decade has given us an entirely new perspective on our understanding of breast milk. We already knew it was packed with an impressive lineup of proteins, enzymes, lipids, sugars, hormones, immune cells, and minerals. But scientists discovered something unexpected in that mix: **oligosaccharides**, complex sugars that make up roughly a third of the milk's composition. And here's the twist: the human body can't even digest them!

These sugars aren't for the baby at all—they're for the baby's bacteria. Oligosaccharides are **prebiotics**, meaning they exist specifically to feed and support the growth of beneficial microbes in the infant's gut. Think about what that means. Human milk didn't evolve solely to nourish a child. It evolved to nourish the invisible community that keeps that child healthy.

Two hundred million years before anyone invented a supplements aisle, early mammal mothers were already doing this. Their milk was fermenting sugars, helping bodies absorb minerals, and fine-tuning immune systems through microbes they were quietly feeding. The story of milk, therefore, isn't just about nutrition—it's about what we mean when we say *us*, and it gives a whole meaning to the saying that "it takes a village" to raise a child (Bohannon 2023, 35-38).



Figure 7.3: Human baby held in adult human hands. Photo by Isaac Quesada on Unsplash.

Source: Bohannon, C. (2023). *Eve: How the Female Body Drove 200 Million Years of Human Evolution*. New York: Alfred A. Knopf.

This is Your Story

You can read these words, plan your weekend, recognize your friends' faces in a crowd. You can grip a pencil, scroll on your phone, and feel textures with your fingertips. None of that is accidental. Every one of those abilities traces back to a set of traits that first appeared in a small, tree-dwelling creature 63 million years ago. In this chapter, we'll examine what makes a primate a primate and in doing so, begin to understand how evolution shaped the very mind you're using right now to read this sentence.

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7.1: Traits of Primates

What Makes a Primate a Primate?

If someone asked you to name a primate, you'd probably say "monkey" or "chimpanzee" without hesitation. As you'll learn in these next few chapters, these are two very different types of primates among a vast array of others.

Primates are one of at least twenty groups, called **Orders**, within the **Class** Mammalia. All mammals share a set of core traits: they have fur or hair, females produce milk from mammary glands, and they are warm-blooded. Most mammals also give birth to live young and nurse them after birth. Primates belong to this group, and today the Order Primates includes lemurs and lorises, tarsiers, monkeys from the Americas and Africa and Asia, apes, and us.

What unites all of these animals is a shared collection of anatomical, behavioral, and life history characteristics. Before we start to dig in to what those traits are, it helps to understand how scientists think about traits in the first place.



Figure 7.1.1: Female macaque monkey with baby. Photo by Lewis Roberts on Unsplash.

It's All Relative

When scientists study how different primates are related to one another, they pay close attention to specific types of traits. Two of the most important categories are **primitive traits** and **derived traits**.

A primitive trait is one that an animal inherited from a distant ancestor and that is shared broadly across many species. For example, all primates have body hair. But that is not because there is something uniquely primate-like about hair. It is because all mammals share a common ancestor from hundreds of millions of years ago that had body hair, and that trait has been passed down ever since. So body hair does not help us figure out whether monkeys are more closely related to apes or lemurs because all of them have this trait.

A derived trait, by contrast, is one that evolved more recently and is shared only by a smaller, more closely related group of species. Human bipedalism (walking on two legs) is a good example. The physical adaptations that allow humans to walk upright evolved after our lineage split from the common ancestor we shared with our closest relatives, chimpanzees and bonobos. So if a fossil species shows those same bipedal adaptations, we can reasonably conclude that it is more closely related to us than to chimps.

Here is an important nuance though: the terms "primitive" and "derived" are relative. It depends on what you are comparing. Body

hair is primitive among primates (everyone has it), but it is derived when you zoom out and compare mammals to fish and birds (hair evolved in mammals after they diverged from these other groups). Context is everything.

It is also worth noting that when one lineage splits into two, one branch often stays more similar to the ancestral form (retaining primitive traits), while the other branch changes more dramatically (developing derived traits). This pattern will come up again when we discuss the two major subgroups of primates, Strepsirrhini (the Prosimians) and Haplorrhini (the Anthropoids).

Two other useful categories are **generalized traits** and **specialized traits.** Think of a generalized trait like a Swiss Army knife: it is useful in a lot of different situations, even if it is not the best tool for any single job. Opposable thumbs are the perfect example. You can use them to grip a branch, scroll through TikTok, open a bag of chips, strum a guitar, or squeeze the last bit of toothpaste out of the tube. Specialized traits, on the other hand, are highly modified for one specific purpose. A horse's hoof is a specialized trait: it's great for running at speed across open ground, but completely useless for grabbing anything. As we will see, most primate traits tend to be generalized, which has given our Order an incredible degree of flexibility.

The Primate Package

No single trait makes an animal a primate. Instead, primates are identified by a collection of characteristics that taken together, set them apart from other mammals. Any one of these traits might appear in a non-human primate, but if you see an animal that has most of all of them, you are almost certainly looking at a primate.

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7.1.1: Eyes and Hands

Enhancements to Vision

All animals, including humans, rely on all of their senses to navigate both the physical and social landscapes, but some senses may be relied on more heavily than others. In the case of primates, this would be vision, and it shows up in our skulls and our brains. Walk into a room full of other primates, a classroom full of students, for example, and you will notice that everyone's eyes face forward. This is called convergent vision, and it gives us overlapping visual fields in both eyes, producing 3-D or **stereoscopic vision** which is key for depth perception. This is what enables you to catch a ball, thread a needle, or judge whether that parking spot is actually big enough. For non-human primates, that depth perception is absolutely essential for accurately judging the distance and depth between branches in order to move safely and swiftly through the trees. The tradeoff is that primates have limited field of view on the sides and can't see behind us particularly well.

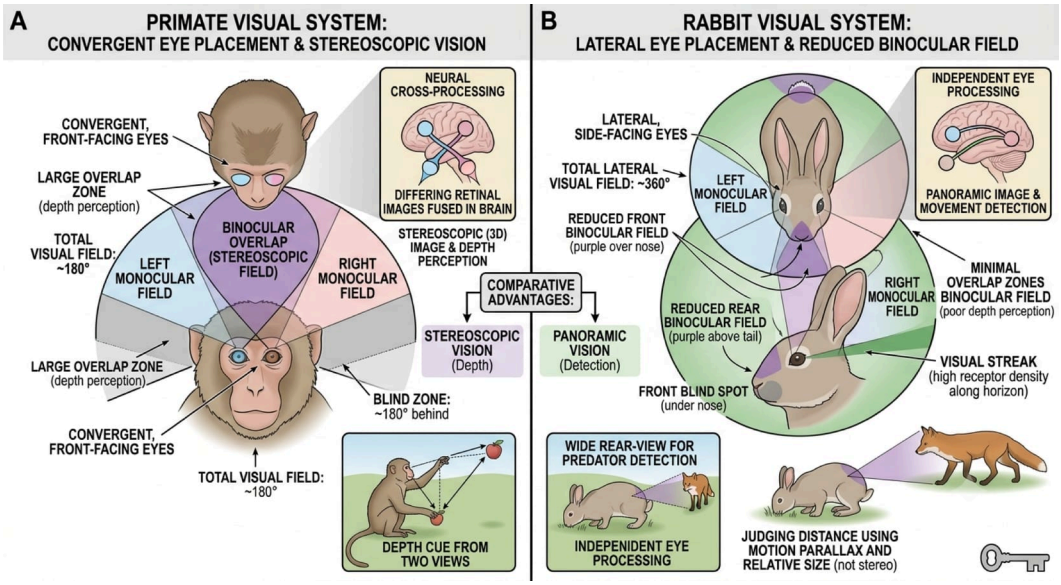


Figure 7.1.1.1: Comparison of primate and rabbit visual system illustrating the difference between visual fields. Image produced by Google Gemini.

You can always turn to the skeletal anatomy for clues as to what sense an animal relies upon most. Since the eyes are the primary sense organs used by primates, they are well protected in their sockets by a **post-orbital bar**, and in those with the most forward facing eyes, are more even more enclosed by a **postorbital plate**—a bony wall at the back of the eye socket.

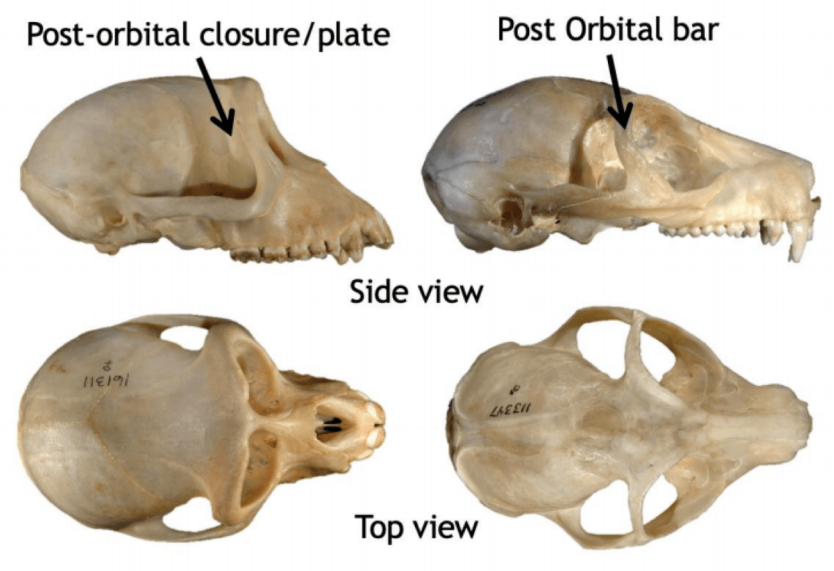


Figure 7.1.1.2: Post-orbital bar/Post-orbital closure a derivative work original to Explorations: An Open Invitation to Biological Anthropology by Stephanie Etting is under a CC BY-NC-SA 4.0 License. [Includes Otolemur crassicaudatus (greater galago) by Animal Diversity Web, CC BY-NC-SA 3.0; Macaca fascicularis (long-tailed macaque) by Animal Diversity Web, CC BY-NC-SA 3.0.]

Many primates also have **trichromatic color vision**, meaning they can see reds and yellows in addition to blues and greens. This is actually somewhat unusual in the mammal world. Most mammals, including dogs, see only in blues and greens (dichromacy), a trait that appears to be a holdover from our nocturnal mammalian ancestors who prioritized night vision over color. Interestingly, birds, fish, and reptiles and even some insects, like bees, can see ultraviolet light, making them the true color vision champions of the animal kingdom. For example, a flower that looks plain yellow to you is covered in elaborate UV patterns that bees can see clearly, helping guide them directly to the nectar and pollen inside.

Why did some primates re-evolve the ability to see more colors? Scientists are still debating this. Some researchers argue it helps with finding ripe fruits or spotting young leaves against a sea of green (Dominy and Lucas 2001; Regan et al. 2001). Others suggest it is useful for detecting predators, particularly big cats, whose coats stand out in a trichromatic visual system (Pessoa et al. 2014). Still others point to social functions, like detecting subtle color changes in the skin that signal emotion or reproductive status (Changizi et al. 2006). What complicates this picture is evidence that dichromatic individuals (who lack full color vision) are sometimes better at seeing through camouflage, which could help with spotting hidden food or predators (Morgan et al. 1992). The bottom line is that here is a lot of variation in color vision across primate species and its evolution remains an interesting and ongoing avenue of research.

A Reduced Sense of Smell

Running a high-powered visual system is expensive in terms of energy. The body compensates by scaling back other senses, particularly smell. Compared to most other mammals, primates have shorter, less prominent snouts. This is another derived trait visible even in our earliest ancestors. The trade-off follows a predictable pattern: primates with more forward-facing eyes and sharper vision tend to have shorter snouts and a weaker sense of smell, while those with less convergent eyes tend to have longer snouts and rely more on smell. Every organism has a limited energy budget, and evolution reflects the compromises that result.

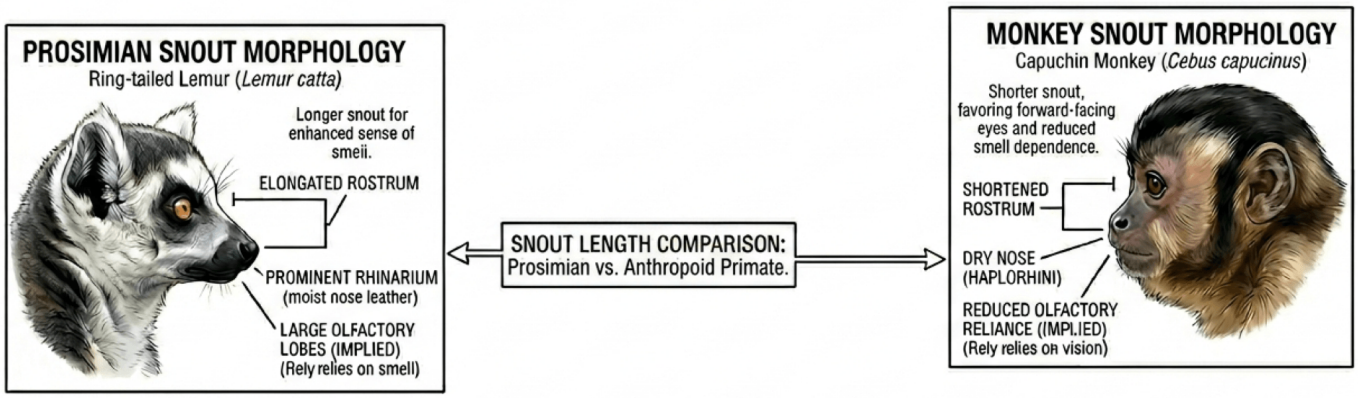


Figure 7.1.1.3: Comparison of snout length between a ring-tailed lemur, a primate that relies more on smell, and a capuchin monkey, which relies more on vision. Image produced by Google Gemini.

Grasping Hands

Being **arboreal**, most primates spend a significant part of their lives in trees, and their hands and feet reflect this. Primates retain the primitive mammalian trait of **pentadactyly**, meaning five digits on each limb. Many other mammals have lost digits over evolutionary time because they are specialized for fast, ground-level running. Primates kept all five, and then took it even further: we evolved **opposable thumbs** and (in all primates except humans) **opposable big toes**. These divergent digits allow primates to wrap their hands and feet around branches, but also to pick up, manipulate, and examine objects with precision. This trait appeared approximately 55 million years ago in the earliest primates.

Complementing the opposable digits are flat **nails** (rather than claws or hooves) on the backs of our fingers and toes, paired with sensitive **tactile pads** on the fronts. This combination gives primates a remarkably refined sense of touch and the ability to handle small objects with care. Primates use this ability not just for finding and processing food, but for **grooming**: the careful combing through another individual's fur that serves as one of the primary ways primates build and maintain social relationships. In many species, who you groom and how often you do it is a measure of your social alliances.



Figure 7.1.1.4: Crab-eating macaques grooming. Photo by Cecilia Jørgensen on Unsplash.

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7.1.2: Teeth and Diet

Dental Characteristics

Teeth might not be the first thing that comes to mind when you think about primates, but they are a highly informative part of the skeleton. They reflect what an animal eats, how it relates to other species evolutionarily, and even how males and females compete for mates. They also preserve exceptionally well in the fossil record, since enamel is extremely durable and predators rarely chew up jaw bones. This means that teeth and jaw fragments make up a large portion of what we actually find as fossils, so learning to extract information from them is a core skill in biological anthropology.

One of the defining features of mammals, including primates, is that we have multiple types of teeth, each designed for a different job. This is called **heterodont** dentition, and it sets us apart from animals like sharks or crocodiles, which have rows of identical, pointed teeth (**homodont** dentition). Mammals have four tooth types: **incisors** for slicing, **canines** typically used as weapons and for defense, and **premolars** and **molar**s for grinding and processing food.

It's important to point out that in most non-human primates, canines are long and conical and can be **sexually dimorphic**, meaning male canines are often noticeably larger than female canines. Many primates also hone their canines by gnashing them against adjacent teeth, keeping them razor sharp. When canines get large enough, the jaws need a small gap to accommodate them when the mouth closes. This gap is called a **diastema** and is a useful feature to recognize when looking at primate skulls.

The Dental Formula

The specific number of each tooth type an animal has is called its **dental formula**, which counts the incisors, canines, premolars, and molars in one quarter of the mouth (half of either the upper or lower jaw). It is written as four numbers separated by colons. Humans, for example, have a dental formula of 2:1:2:3, meaning two incisors, one canine, two premolars, and three molars in each quadrant. Among living primates, the maximum dental formula is 2:1:3:3, though many species have fewer teeth than this, and some have different formulas on the top versus the bottom jaw.

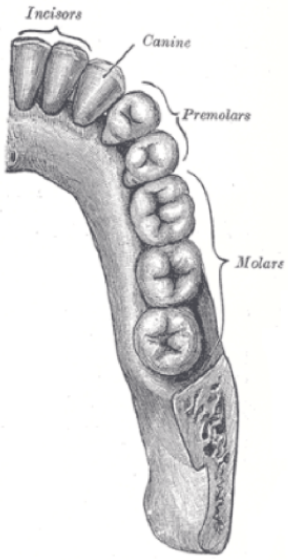


Figure 7.1.2.2: This drawing shows half of the human mandible. With the four types of teeth labeled, you can determine that the dental formula is 2:1:2:3. Credit: Gray997 by Henry Vandyke Carter, original in Henry Gray (1918) Anatomy of the Human Body, Plate 997, is in the public domain.

To use a dental formula, you need to be able to identify the tooth types. Incisors tend to look like small spatulas with a flat, blade-like edge. Canines are usually the easiest to spot because they are longer and more pointed than the rest. Premolars and molars are distinguished mainly by size and the number of **cusps**, the small bumps on the chewing surface that you can feel with your

tongue on your back teeth. Premolars are smaller and typically have one or two cusps. Molars are larger with a broader chewing surface and anywhere from three to five cusps depending on the species and whether you are looking at upper or lower teeth.

Teeth and Diet

Primates are dietary generalists, meaning most species eat a mix of fruits, leaves, insects, seeds, and occasionally other foods. What varies across species is the proportion of each item in the diet, and those proportions are written into the teeth. The three main dietary categories among primates are **frugivores** (fruit-eaters), **insectivores** (insect-eaters), and **folivores** (leaf-eaters).

Frugivores have it relatively easy, dietarily speaking. Plants actually want animals to eat their fruits because doing so disperses the seeds. As a result, fruits are colorful, sweet, and easy to chew and digest. Frugivores tend to have broad molars with low, rounded cusps (called **bunodont** molars) that are well-suited to mashing soft food, along with large incisors for breaking through fruit skins. Because fruit is low in protein, frugivores supplement their diet with insects or leaves. Some frugivores that rely heavily on hard seeds have evolved thicker tooth enamel to handle the extra wear.

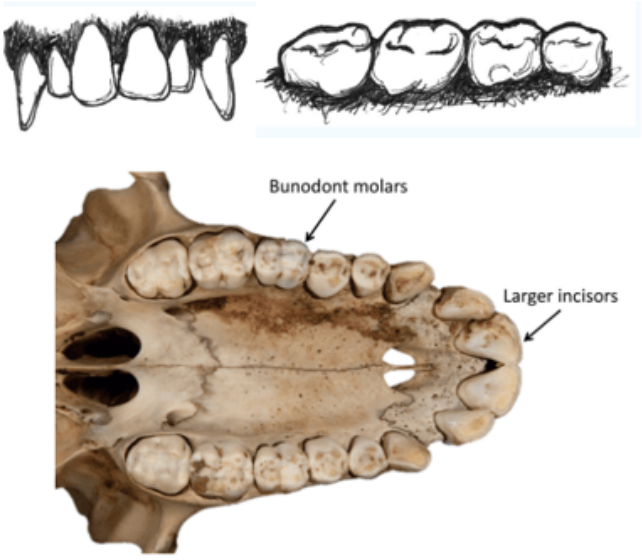


Figure $7.1.2.3a-c$: Frugivores are characterized by large incisors, bunodont molars, and digestive tracts that are intermediate in complexity between the other two dietary types. Clockwise from top left: a) Illustration of large incisors of a frugivore and b) Illustration of bunodont molars of a frugivore. Image credit: Frugivore characteristics original to Explorations: An Open Invitation to Biological Anthropology by Mary Nelson is under a CC BY-NC 4.0 License; c) Frugivore maxilla with teeth labeled. Image credit: Papio papio (Guinea baboon).jpg by Phil Myers on Animal Diversity Web is under a CC BY-NC-SA 3.0 License.

Insectivores face the opposite challenge: insects are hard to find and catch but easy to chew once you have them. Insectivorous primates tend to have small molars with sharp, pointed cusps designed to puncture insect exoskeletons. Because insects are relatively easy to digest, insectivores have simple digestive systems. The catch is that insects are not abundant enough in most environments to fuel large bodies, so insectivorous primates tend to be the smallest members of the Order.

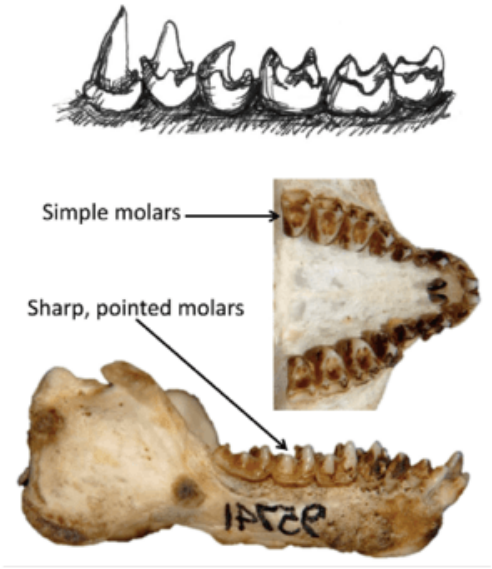


Figure $7.1.2.4a-b$: Insectivores need sharp, pointed molar cusps in order to break through the exoskeletons of insects. Insects are easy to digest, so these primates have simple digestive tracts. From top to bottom: a) Illustration of sharp teeth of an insectivore. Image credit: Insectivore characteristics original to Explorations: An Open Invitation to Biological Anthropology by Mary Nelson is under a CC BY-NC 4.0 License; b) Mandible and maxilla of an insectivore with molar features highlighted. Image credit: Tarsier's (an insectivore) teeth original to Explorations: An Open Invitation to Biological Anthropology (2nd ed.) by Stephanie Etting is a collective work under a CC BY-NC-SA 3.0 License. [Includes Lower_lateral1942 by Phil Myers on Animal Diversity Web, CC BY-NC-SA 3.0; Ventral by Phil Myers on Animal Diversity Web, CC BY-NC-SA 3.0.]

Folivores have the hardest job. Plants generally don't want to be eaten and have evolved an arsenal of defenses in their leaves: toxins, bitter compounds, tough fibrous structures, and complex cellulose molecules that are difficult to break down into usable energy. To get around this, folivorous primates have evolved broad molars with high, sharp cusps connected by **shearing crests** that physically shred fibrous leaf material during chewing. They also have specialized digestive systems with large intestines, long guts, and bacteria capable of breaking down cellulose. Some folivores have multi-chambered stomachs similar to cows. Because leaves are abundant and do not require much effort to find, folivores tend to be the largest-bodied primates, but they pay for it by spending a significant portion of their day resting and digesting.

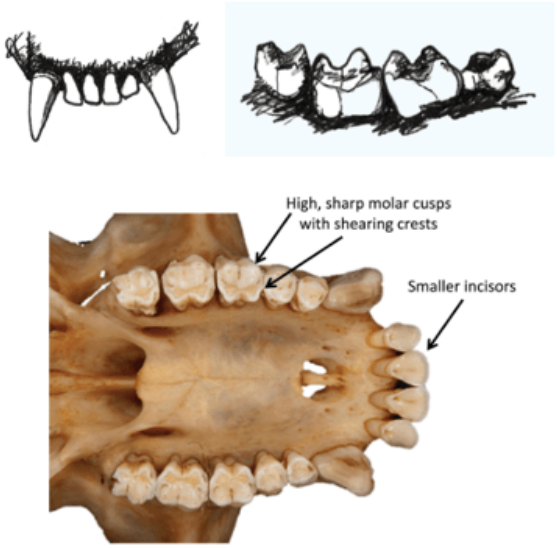


Figure $7.1.2.5a-c$: In order to derive energy from leaves, folivores have smaller incisors, high, sharp molar cusps connected by shearing crests and complex digestive tracts filled with specialized bacteria. Clockwise from top left: a) Illustration of small incisors of a folivore and b) Illustration of crested molars of a folivore. Image credit: Folivore characteristics original to Explorations: An Open Invitation to Biological Anthropology by Mary Nelson is under a CC BY-NC 4.0 License; c) Maxilla of a folivore with characteristic tooth features highlighted. Image credit: Trachypithecus obscurus (dusky leaf monkey) upper teeth by Phil Myers on Animal Diversity Web has been modified (background removed, labels added by Stephanie Etting) is under a CC BY-NC-SA 3.0 License.

A useful way to remember these patterns is that as you move from insectivores to frugivores to folivores, body size generally increases and molar cusps go from sharp and pointed to low and rounded to high and crested. The teeth are essentially a map of the diet.

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7.1.3: Locomotion

Getting Around: Primate Locomotion

One of the things that makes primates fascinating is how many different ways they get around. Most animals are specialists, built for one primary mode of movement. Primates, by contrast, are locomotor generalists, and across the Order you find animals that climb, leap, swing, scamper, walk, and hang, sometimes all in the space of the same afternoon. The four main locomotor patterns seen in living primates are **vertical clinging and leaping**, **quadrupedalism**, brachiation, and **bipedalism**, and each comes with its own set of anatomical specializations.

Vertical clinging and leaping is exactly what it sounds like. The animal clings upright to a vertical branch, pushes off with its powerful hind legs, and launches itself to another vertical support, landing feet-first. Animals that move this way tend to have longer legs than arms, long fingers and toes for gripping, and notably elongated ankle bones that function like a springboard, giving extra leverage on the push-off.

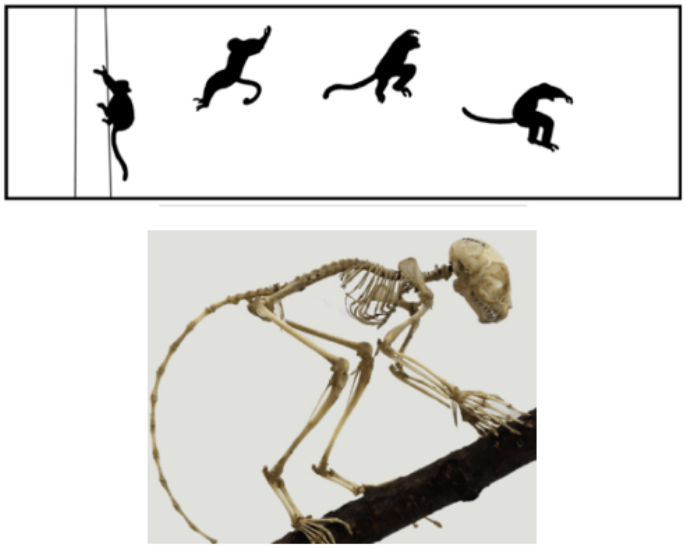


Figure $7.1.3.1a-b$: Vertical clingers and leapers have longer legs than arms, long lower backs, and long fingers and toes. They also have elongated ankle bones to help them push off when leaping. From top to bottom credit: a. Propithecus vertical clinging and leaping by Terpsichores is under a CC BY-SA 3.0 License. b. Tarsier skeleton by Emőke Dénes has been modified (background removed) by Stephanie Etting and is under a CC BY-SA 4.0 License. Original Spectral tarsier (Tarsius tarsier) skeleton at the Cambridge University Museum of Zoology, England.

Quadrupedalism, moving on all fours, is the most common locomotor pattern among primates, and you probably picture it anytime you think of a monkey walking along a branch or a baboon crossing an open field. The details vary depending on where a species spends most of its time. Arboreal quadrupeds tend to have shorter limbs and longer tails, which help lower their center of gravity and maintain balance on narrow, unstable branches. Terrestrial quadrupeds have longer limbs for covering ground efficiently and often shorter tails, since balance on flat terrain is less of a challenge.



Figure $7.1.3.2a-b$: Two examples of quadrupedal primates. The capuchin monkey skeleton on the left (a) is a typical arboreal quadruped with shorter arms and legs, longer fingers and toes, and a long tail. The baboon skeleton on the right (b) is a terrestrial quadruped with relatively long arms and legs, shorter fingers and toes, and a short tail. Credit: a. Capuchin monkey skeleton by Henri-Marie Ducrotay de Blainville is in the public domain. b. Baboon by Henri-Marie Ducrotay de Blainville is in the public domain.

Brachiation is the one you have personal experience with, if you ever played on "monkey bars" as a kid (monkeys can't actually brachiate, so really these would be more appropriately called "ape bars"). Brachiators swing below branches hand over hand, using their arms like pendulums. It is an efficient and fast way to move through a forest canopy, but it requires a very specific body plan: arms longer than legs, highly mobile shoulders and wrists, a short and stiff lower back, and no tail. These are precisely the traits you see in apes, and we will return to them in the next chapter.





Figure $7.1.3.3a-b$: From top to bottom a) Example of brachiation. Image credit: Produced by Google Gemini and b) A brachiating ape's skeleton. Image credit: Brachiator original to Explorations: An Open Invitation to Biological Anthropology by Mary Nelson is under a CC BY-NC 4.0 License.

Some primates practice **semi-brachiation**, a hybrid strategy. They swing below branches like brachiators but also walk on all fours when on the ground, so their arms and legs are more similar in length. What sets semi-brachiators apart is their **prehensile tail**, a fully grasping tail that functions as a fifth limb. The underside of the tail even has a tactile pad, similar to the fingerprint ridges on your hands, for a better grip. This is a feature found only in some New World monkeys, making it one of the more distinctive traits in the primate world.



Figure 7.1.3.4: Spider monkeys are considered semi-brachiators, as they can swing below branches but use their tails as a fifth limb. On the ground they move via quadrupedal locomotion. Credit: Ateles-fusciceps 54724770b by LeaMaimone is under a CC BY 2.5 License.

Finally, there is **bipedalism**: walking upright on two legs with a striding gait. Other primates will occasionally stand and walk on two feet, but they do so awkwardly and only for short distances. Humans are the only mammals who have evolved full-time striding bipedalism as a primary way of getting around, and it required a sweeping set of anatomical changes to the skeleton that we will explore in depth in later chapters.

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7.1.4: Brains, Development, Behavior

Big Brains

Primates have notably large brains relative to their body size. On average, a primate's brain is about twice as large as you would expect for a mammal of the same size. The visual processing centers are especially enlarged, reflecting our dependence on sight. The **neocortex**, the region associated with higher-level thinking, sensory perception, and spatial awareness (and in humans, language and self-awareness), is also proportionally larger in primates than in other mammals. In many non-primates, the neocortex is relatively smooth, while in primates it is folded into many ridges and grooves, which dramatically increases its surface area.

Two competing hypotheses attempt to explain why primate brains got so big. One focuses on diet: finding and processing fruits requires more cognitive work than eating leaves, and fruit-eating primates do tend to have larger relative brain sizes (Clutton-Brock and Harvey 1980). The other hypothesis focuses on social complexity: living in large, dynamic social groups requires keeping track of many relationships, alliances, and rivalries, which demands significant brainpower (Dunbar 1998). Current evidence suggests both pressures likely played a role.



Figure 7.1.4.1: Macaque family huddled together. Photo by Suprem Vanam on Unsplash.)

Life in the Slow Lane

Animals with large brains tend to grow slowly, reproduce less frequently, and live long lives, and primates are no exception. Compared to other mammals of similar body size, primates take longer to mature, have fewer offspring per pregnancy (usually just one), wait longer between births, and live significantly longer. A few exceptions exist. Some small New World monkeys regularly give birth to twins, and certain lemurs can produce multiple offspring at once, but these are outliers in the primate world.



Figure 7.1.4.2: Female ring-tailed lemur and baby. Image by Phalia from Pixabay.

A few exceptions exist. Some small New World monkeys regularly give birth to twins, and certain lemurs can produce multiple offspring at once, but these are outliers in the primate world. Among primates, the orangutan takes the slow strategy to an extreme: females typically give birth only once every seven to nine years, making them the slowest-reproducing mammals on Earth.

The payoff for this slow pace is longevity and deep parental investment in each offspring. Some large-bodied apes are estimated to live up to 58 years in the wild, and among great apes, offspring may stay close to their mothers for a decade or more after birth (Robson et al. 2006).



Figure 7.1.4.3: Female orangutan with baby. Photo by Bob Brewer on Unsplash.

Social Lives

Primates are intensely social animals. Research has shown that strong social bonds in primates are linked to lower stress, better health, and greater reproductive success (Silk et al. 2009). The long-term, stable social relationships primates form over their lifetimes lead to some rather complex and fascinating behaviors that we'll learn about in more depth in the next chapter.

Behavioral Adaptations

Chapter 9 is dedicated to primate behavior, so this is just a brief summary of the variations in activity patterns, social grouping, and habitat use. Primate groups often differ in **activity patterns**—that is, whether they are active during the day (**diurnal**), at night (**nocturnal**), or through the 24-hour period (**cathemeral**). We also see variations among primate groups in social groupings: some taxa are primarily solitary, others live in pairs, and still others live in groups of varying sizes and compositions. Lastly, some taxa are primarily arboreal while others are more terrestrial.

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7.1.5: Habitat and Threats

Where Primates Live

It might surprise you to learn that tropical rainforests cover only about 6% of Earth's land surface, yet they are home to nearly half of all living species on the planet, including around 90% of all primate species. Rainforests are structured in distinct vertical layers, from the emergent layer at the very top (think: the tallest trees poking above the rest of the canopy) down through the canopy, understory, and forest floor.

Primates have carved out niches at virtually every one of these levels, with different species specializing in different heights, food sources, and activity patterns. This vertical partitioning reduces direct competition between species, which is part of how so many different primates can share the same patch of forest. Most non-human primates are found in tropical regions, concentrated between the Tropic of Cancer and the Tropic of Capricorn, with only a few species living outside those latitudes.

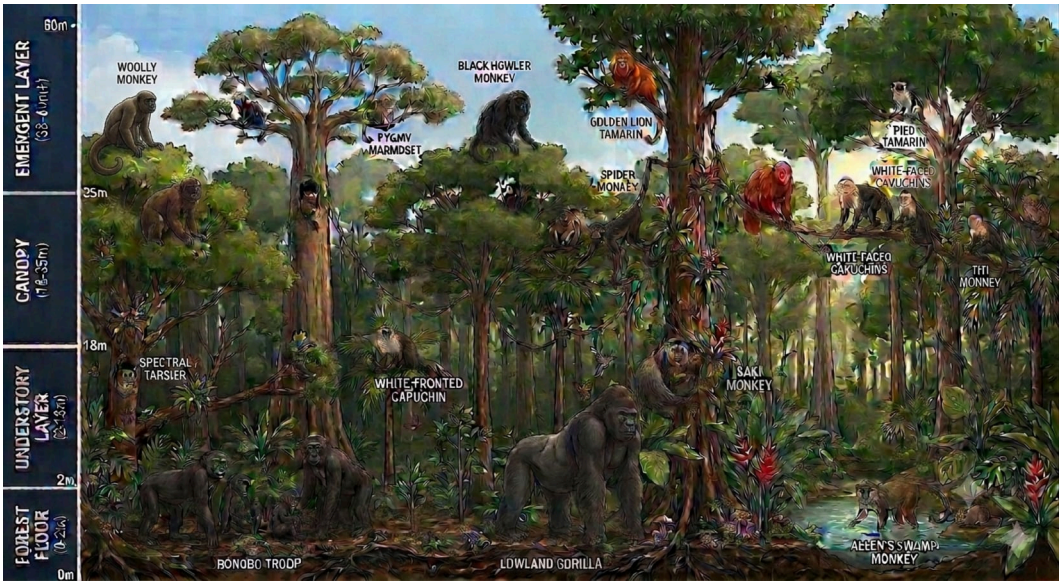


Figure 7.1.5.1:Forest Layers with various species of primates found in them. Graphic image produced by Google Gemini. **Note**: The primate species shown together in this illustration are found across different regions of the world (the Americas, Africa, and Asia) and would not naturally co-occur in a single forest. They've been combined here for educational purposes to demonstrate how different primate species occupy different vertical layers within a forest ecosystem.

Threats

Despite their adaptability, primates face serious and growing threats, almost all of them driven by human activity.



Figure 7.1.5.2: Deforestation in Ecuador. Image by A.Davey, CC BY 2.0 via Wikimedia Commons.

Habitat loss is the most widespread threat. Tropical deforestation for agriculture, logging, and development continues to shrink and fragment primate habitats at an alarming rate. Because primates are concentrated in tropical regions, the destruction of these forests disproportionately impacts them. A species with a small geographic range can be pushed to the edge of extinction by the clearing of a relatively small area.

Hunting for bushmeat is a significant issue across parts of Africa and Asia, where primates are killed for food. Larger-bodied primates, which reproduce slowly, are especially vulnerable because their populations cannot recover quickly from hunting pressure.

The illegal wildlife trade poses another serious threat. Infant primates are captured and sold as exotic pets, a practice that involves killing the mother (and often other members of the social group) to obtain the infant. Viral videos of baby apes in domestic settings have unfortunately fueled demand for them as pets. It is a grim irony that our shared traits with other primates, including their expressiveness and social behaviors that remind us of ourselves, make them targets for this exploitative trade.

Did You Know?

Great Apes in Crisis: A Shifting Threat

Great apes have faced human threats for generations, but the nature of those threats is changing and the consequences are accelerating. Understanding this shift is essential for anyone studying the relationship between human behavior and primate survival.

For most of recent history, the capture of baby gorillas and chimpanzees was considered a grim side effect of the bushmeat trade. Adult apes were killed for meat, and any surviving infants were taken and sold as pets. Today, that dynamic has completely reversed. Baby apes are now the primary target. Traffickers receive orders from clients in advance and dispatch hunters specifically to fill them. As one anti-trafficking expert put it, the trade is no longer opportunistic. It is deliberate and demand-driven.



Figure 7.1.5.3: A baby gorilla. Photo by Bob Brewer on Unsplash.

The Social Media Effect

What drove this shift? Researchers point to social media. Videos featuring chimpanzees and gorillas in human domestic settings—wearing clothes, eating at tables, cuddling with people—routinely generate millions of views. For most viewers, these videos are simply entertaining. But for a small and dangerous fraction, they inspire something more: the desire to own one.

An activist group reviewing social media platforms in 2017 identified over 260 chimpanzees and orangutans that appeared to have been trafficked, their images casually posted online. The demand this content generates has turned baby apes into high-value commodities, with individual animals selling for hundreds of thousands of dollars. Traffickers now actively use private social media channels to advertise animals for sale, connecting with wealthy buyers across the Middle East, Asia, and beyond.

The True Cost of Capture

What many buyers, and social media viewers, don't consider is what capturing a single baby ape actually requires. Gorillas are intensely protective of their young. To take one infant alive, hunters must typically kill multiple adults in the group first. Every baby ape entering the illegal trade represents the destruction of an entire family unit. For a species already listed as critically endangered, that toll is catastrophic.



Figure 7.1.5.4: Young chimpanzee in Beijing Zoo is in the public domain via Wikimedia Commons.

A Systemic Problem

Compounding the crisis is widespread corruption in the legal systems designed to prevent it. International treaties give governments the authority to issue permits for transporting endangered animals (not just apes) across borders—a safeguard that has been routinely abused. Officials in some countries have sold or pre-signed blank permits, effectively laundering illegal shipments into legal ones. Traffickers operate with considerable confidence, knowing that enforcement is inconsistent and penalties, if they happen at all, are often light.

What We Can Do

The illegal ape trade is entirely human-made, which means it can be solved by humans. Stronger enforcement and international cooperation are essential, but individual behavior matters too. Being mindful of the content we engage with and share online—particularly videos featuring wild animals in domestic settings—is a small but meaningful step. The market for exotic apes exists because human desire created it. Reducing that desire is the first step in working towards lasting change.



Figure 7.1.5.5: Primates are Not Pets. Image produced by Google Gemini.

Source: Bhattacharjee, Y. (2026, Mar 15). Bili's Journey. *New York Times Magazine,* 22-25,45,45A.

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7.2: Learning from Primates

Homologies and Analogies

While primates are fascinating animals in their own right, we study non-human primates in anthropology with the ultimate goal of understanding more about our own biology and evolutionary history. There are two main ways non-human primates can help illuminate human evolution. The first is through **homology**, that is, traits that are shared between species because they inherited them from a common ancestor. Humans and chimpanzees, for example, share a good deal of physical and behavioral traits. Because both species have them, those traits were almost certainly present in the common ancestor we shared roughly 6 to 8 million years ago.

The second way is through **analogy**, also called convergent evolution. This is when two species independently evolve similar traits because they face similar environmental pressures, not because they share a recent common ancestor. Baboons and humans are a good example. Both have relatively long legs, but not because they inherited that trait from the same ancestor. Rather, both species moved into open savanna environments where covering large distances efficiently was a survival advantage, and longer legs solve that problem. The same selective pressure, acting on two different lineages, produced the same solution. When we understand why baboons evolved a particular trait, it can give us strong clues about why our own ancestors did too.

Together, homology and analogy make non-human primates valuable for understanding the forces that shaped human evolution, which is exactly why they are a part of biological anthropological study.

Conclusion

The Order Primates is a diverse and fascinating group of animals united in sharing a suite of characteristics—visual specialization, grasping hands and feet, large brains, and extended life histories—that differentiates us from other groups of mammals. In this chapter, we laid the foundation for exploring the great diversity of species that make up the Primate Family Tree and where humans fit into this larger primate picture.

You can see a summary of the primate suite of traits in the box below:

- Convergent (forward facing) eyes
- Post-orbital closure
- Many have trichromatic vision
- Short snouts
- Grasping hands
- Opposable thubs and big toes
- Pentadactyly (five digits on hands and feet)
- Flattened nails
- Tactile pads
- Large brains
- Extended life histories
- Highly social and intelligent
- Highly arboreal
- Live in the tropics

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7.3: Key Terms

Key Terms

Activity pattern – refers to the time of day an animal is typically active.

Analogy – when two or more taxa exhibit similar traits that have evolved independently, the similar traits evolve due to similar selective pressures (also sometimes called *convergent evolution*, *parallel evolution*, or *homoplasy*).

Ancestral (primitive) trait – a trait that has been inherited from a distant ancestor.

Arboreal – a descriptor for an organism that spends most of its time in trees.

Bipedalism – walking on two legs.

Brachiation – a form of locomotion in which the organism swings below branches using the forelimbs.

Bunodont – low, rounded cusps on the cheek teeth.

Canines – in most primates, these are the longest of the teeth, often conical in shape and used as a weapon against predators or others of their species.

Cathemeral – active throughout the 24-hour period.

Class – a taxonomic rank that sits immediately below a phylum and above an order in biological classification, grouping together a collection of related, structurally, or evolutionarily similar orders.

Cusps – the bumps on the chewing surface of the premolars and molars, which can be quite sharp in some species.

Dental formula – the number of each type of tooth in one quadrant of the mouth, written as number incisors: canines: premolars: molars.

Derived trait – a trait that has been recently modified, most helpful when assigning taxonomic classification.

Diastema – a space between the teeth, usually for large canines to fit when the mouth is close.

Diurnal – active during the day.

Folivore – having a diet consisting primarily of leaves.

Frugivore – having a diet consisting primarily of fruit.

Generalized trait – a trait that is useful for a wide range of tasks.

Grooming – technique of using thumbs, fingers, hands, and teeth to part hair, inspect skin, and remove dried skin. Non-human primates use this primarily to build trust, establish alliances, manage stress, and mediate conflict.

Heterodont – having different types of teeth.

Homodont – having only one type of tooth.

Homology – when two or more taxa share characteristics because they inherited them from a common ancestor.

Incisors – the spatula-shaped teeth at the front of the mouth.

Insectivore – having a diet consisting primarily of insects.

Molars – the largest teeth at the back of the mouth; used for chewing, in primates, these teeth usually have between three and five cusps.

Neocortex – complex and most recently evolved brain structure in mammals that commands higher function such as perception, emotion, and cognition.

Nocturnal – active at night.

Oligosaccharides – short-chain carbohydrates composed of simple sugar molecules linked together

Opposable thumbs/big toes – having thumbs and toes that go in a different direction from the rest of the digits, allowing for grasping with hands and feet.

Order – a mid-level rank in biological classification that sits immediately below a Class and directly above a Family.

Pentadactyly – having five digits or fingers and toes.

Post-orbital bar – a bony ring that surrounds the eye socket, open at the back.

Post-orbital plate/closure – a bony plate that provides protection to the side and back of the eye.

Prebiotic – a substance (especially a carbohydrate) that is nearly or wholly indigestible and that when consumed promotes the growth of beneficial bacteria in the digestive tract.

Prehensile tail – a grasping tail that is able to hold the full body weight of an organism, which often has a tactile pad on the underside of the tip for improved grip.

Premolars – smaller than the molars, used for chewing. In primates, these teeth usually have one or two cusps.

Quadrupedalism – moving around on all fours.

Semi-brachiation – a form of locomotion in which an organism swings below branches using a combination of forelimbs and prehensile tail.

Sexually dimorphic – when a species exhibits sex differences in morphology, behavior, hormones, and/or coloration.

Shearing crests – sharpened ridges that connect cusps on a bilophodont molar.

Specialized trait – a trait that has been modified for a specific purpose.

Tactile pads – sensitive skin at the fingertips for sense of touch. Animals with a prehensile tail have a tactile pad on the underside of the tail as well.

Trichromatic color vision – being able to distinguish yellows and reds in addition to blues and greens.

Vertical clinging and leaping – a locomotor pattern in which animals are oriented upright while clinging to vertical branches, push off with hind legs, and land oriented upright on another vertical branch.

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8: PRIMATE DIVERSITY

Learning Objectives

- Explain why studying non-human primates is important in anthropology.
- Define different traits used to evaluate primate groups.
- Distinguish between major primate groups using their characteristics.
- Describe your place in nature by learning about primate taxonomic classification.

8.1: Primate Taxonomy

8.2: The Prosimian Suborder

8.3: The Anthropoid Suborder

8.3.1: The Tarsier Infraorder

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8.3.3: Old World Monkeys

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8.3.4.1: Gibbons and Siamangs

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8.5: Key Terms

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8.1: Primate Taxonomy

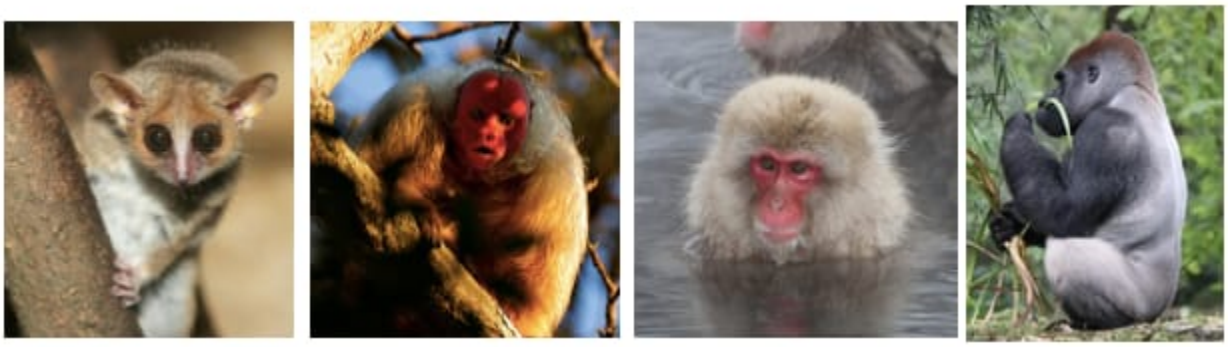


Figure $8.1.1a-d$: Primate species. From left: a) Mouse lemur image by Microcebus murinus -Artis Zoo, Amsterdam, Netherlands-8a by Arjan Haverkamp, CC BY 2.0; b) Uakari monkey, image by Giovanni Mari is licensed under CC BY-SA 2.0; c) Japanese macaque, image by Greg Schecter is licensed under CC BY-SA 2.0; d) Gorilla, image by markapgar from Pixabay.

Introduction

Primates are one of the most diverse groups of mammals on Earth, with over 500 species ranging from the tiny 1-ounce mouse lemur to the 400-pound gorilla. There are acrobatic spider monkeys swinging through South American rainforests, nocturnal tarsiers with eyes bigger than their brains, and tool-using chimpanzees that hunt with spears. Some primates, like the proboscis monkey, have noses so large they hang past their chins, while others, like the bald uakari, have bright red faces that look perpetually sunburned. From the icy mountains of Japan where macaques bathe in hot springs, to the tropical islands of Southeast Asia, to the forests of Madagascar where lemurs evolved in complete isolation—primates have adapted to an incredible range of environments. Included in this group are humans, sharing 98.8% of our DNA with chimpanzees and belonging to the same biological order as all these diverse species. Studying our closest living relatives gives us valuable insights into human evolution, social behavior, and intelligence. As you'll discover in this chapter, understanding primate diversity helps you to understand your own place in the natural world.

Before we dive into the fascinating world of primates, let's talk about how scientists organize living things. Think of **taxonomic classification** like a set of nested boxes, each one fitting inside a larger one. The biggest box is the Order Primates (which includes all primates), and as we open smaller and smaller boxes inside, we get more specific groups until we reach individual species.

Figure 8.1.2 shows you this hierarchy for primates. Try this: find humans on the chart and trace your way up through each category. Notice that as you move up, each level includes more and more species. This means humans share key traits with every group we belong to. Refer back to this figure as we explore each **taxon** (that's the singular form of taxa, meaning a group in this classification system).

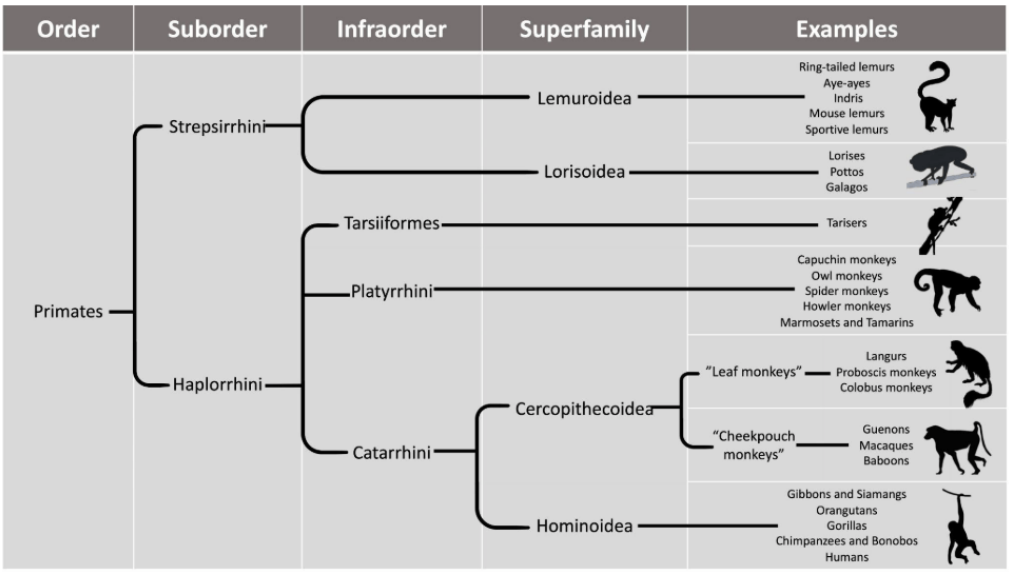


Figure 8.1.2: This taxonomy chart shows the major groups of primate taxa, starting with the largest category (Order) and moving to more specific categories and examples. Credit: Primate taxonomy chart (Figure 5.11) original to Explorations: An Open Invitation to Biological Anthropology by Stephanie Etting is a collective work under a CC BY-NC 4.0 License.[1]

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Primate Groups: The Big Picture

Within the Order Primates, there are three main branches we'll be focusing on: prosimians, monkeys, and apes. These groups tell us about the relationship between different types of primates, including humans. While many scientists classify humans as apes because we share so much of our DNA and physical structure with them, others prefer to put humans in our own special category. Either way, we're definitely part of this primate family tree.

But classification isn't always straightforward. When scientists see genetic and physical (**morphological**) similarities between species, they conclude that those species share a common ancestor—what we call a shared **phylogeny**. Look back at Figure 8.1.2 again. Notice it's not a straight line but a branching tree. That's because evolution doesn't work like a ladder; it's more like a bush with branches spreading in different directions. When you look closely at those branches you'll notice that the monkeys and apes are more closely related to each other, and

share more adaptations in common, than either of them do with the prosimian primates. The classification of primates is actually quite complex, but for our purposes, thinking about primates in these three main groups—prosimians, monkeys, and apes—will give you a solid foundation for understanding the more nuanced details later.

To begin, scientists divide the Order Primates into two major suborders that split about 70–80 million years ago: the **Prosimian** Suborder and the **Anthropoid** Suborder. The scientific names of these groups are *Strepsirrhini* (prosimians) and *Haplorrhini* (anthropoids), but we'll stick with the simpler names since they're more intuitive. It's also helpful to think of the prosimians as "pre-monkeys"—that's actually what their Latin name means. They're the most primitive, or ancestral, primates. Anthropoids, on the other hand, are the more human-like primates: monkeys, apes, and of course, us.

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8.2: The Prosimian Suborder

Our Most Ancient Primate Relatives

Prosimians have retained many traits from the earliest primates, which makes them different from monkeys and apes in fascinating ways. Generally, they're smaller, more likely to be active at night (**nocturnal**), have a better sense of smell, are less social, and eat more insects (**insectivorous**) than other primates. Many prosimians are also incredible leapers, with some groups specializing in a form of locomotion known as **vertical clinging and leaping** (picture a small primate gripping a tree trunk vertically and then launching itself to another tree).

Prosimians have two distinctive features that evolved independently from the anthropoid primates: a **grooming claw** and a **tooth comb** (or dental comb) on their lower front teeth (Figure 8.2.1a-b). Most prosimians have six teeth in this comb—four incisors and two canines—which they use for grooming and feeding.



Figure $8.2.1a-b$:Distinctive prosimian features. From left: a) Grooming claw on the foot of a ring-tailed lemur, image by Lemur catta toilet claw by Alex Dunkel (Maky) is under a CC BY 3.0 License.; b) Tooth comb of ring-tailed lemur showing the six lower teeth of the tooth comb: four incisors and two canines. The teeth that superficially look like canines are premolars, image by Lemur catta toothcomb by Alex Dunkel (Maky) is under a CC BY 3.0 license.

The scientific name *Strepsirrhini* comes from a key feature: prosimians have wet noses called **rhinariums**, just like your cat or dog. Combined with a longer snout, this reflects their much stronger reliance on smell (**olfaction**) compared to monkeys and apes. Many prosimians practice **scent marking,** rubbing scent glands or even urine on objects to communicate with other prosimians about territory, mating status, and more. They also have mobile ears that swivel around to locate insect prey and detect predators.

While prosimians are smell experts, their vision is more primitive than that of anthropoids. Their eyes are less forward-facing (less **convergent**), and though all have **postorbital bars**—a bony ring around the eye—they don't have complete **postorbital closure** like monkeys and apes do.

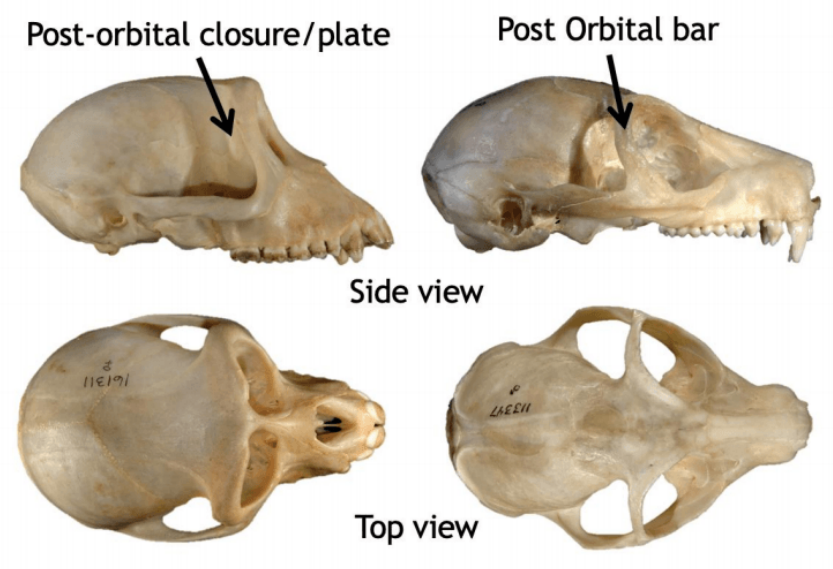


Figure 8.2.2: Full post-orbital closure in an Anthropoid primate on the left, compared to the Prosimian primate on the right with only the postorbital bar. Image credit: Postorbital bar/Postorbital closure (Figure 5.1) a derivative work original to Explorations: An Open Invitation to Biological Anthropology by Stephanie Etting is under a CC BY-NC-SA 4.0 License. [Includes Otolemur crassicaudatus (greater galago) by Animal Diversity Web, CC BY-NC-SA 3.0; Macaca fascicularis (long-tailed macaque) by Animal Diversity Web, CC BY-NC-SA 3.0.]

Prosimians do have one distinctive visual feature: a **tapetum lucidum**, which is a reflective layer at the back of the eye. This layer bounces light back through the eye, helping them see much better in darkness. It's the same structure that makes your dog or cat's eyes glow when you photograph them with a flash. Scientists believe this is an ancestral trait that many early mammals possessed.

You can find prosimians throughout Asia and Africa, but they're particularly diverse on the island of Madagascar. The main groups include lorises, galagos, pottos, and lemurs.



Figure 8.2.3: Geographic distribution of living strepsirrhines. Lemurs live only on Madagascar, while lorises and galagos live across Central Africa and South and Southeast Asia. Credit: Geographic distribution of living strepsirrhines (Figure 5.16) original to Explorations: An Open Invitation to Biological Anthropology by Elyssa Ebding at GeoPlace, California State University, Chico is under a CC BY-NC 4.0 License.

The Lemurs of Madagascar

Lemurs live exclusively on Madagascar, an island off the east coast of Africa where, with no monkeys on the island, they've evolved

into more than 30 different species. Sadly, all of them are now endangered. Some lemurs are **arboreal** (tree-dwelling), while others are **terrestrial** (ground-dwelling). The arboreal ones move primarily by clinging and leaping, so their legs are noticeably longer than their arms. This body structure makes them spectacular leapers in the trees, but on the ground they have to move by hopping on two feet in an upright position, which looks quite comical.



Figure 8.2.4: The sifaka, a type of lemur, shown leaping vertically while on the ground. Image by Charles J. Sharp, CC BY-SA 3.0, via Wikimedia Commons.

Madagascar's isolation is key to understanding lemur diversity. This island broke away from Africa around 130 million years ago and from India about 85 million years ago. When lemurs arrived roughly 60–70 million years ago, they found an island with very few mammal competitors. This allowed them to flourish and diversify into many more forms than their mainland prosimian relatives.

Without competition from other primates, Madagascar's lemurs have adapted to fill many different ecological roles. Some are active during the day, others at night. They range dramatically in size, from the tiny mouse lemur—some species weigh just over an ounce—to the indri, the largest prosimian at about 20 pounds (Figure 8.2.5). Their diets are equally diverse: some species are insectivorous, others are **frugivorous** (fruit-eating), and still others are **folivorous** (leaf-eating). A few have truly unusual diets for primates. For example, **gummivorous** fork-marked lemurs eat tree gum, and bamboo lemurs can actually metabolize the cyanide in bamboo, a poison that would be deadly to most animals.



Figure $8.2.5a-d$: a) Dwarf lemur, image by Nigel Voaden, CC BY 4.0, via Wikimedia Commons; b) Fork-mark dwarf lemur, image by Russell A. Mittermeier, CC BY-SA 4.0, via Wikimedia Commons; c) Bamboo lemur, image by Charles J. Sharp, CC BY-SA 4.0, via Wikimedia Commons; d) Indri, image by Oliver Gärtner, CC BY-SA 3.0 via Wikimedia Commons.

The most unusual lemur is definitely the aye-aye. This strange-looking nocturnal lemur has front teeth like a rodent's that never stop growing. Its most distinctive feature is an extremely long, bony middle finger that it uses to tap on wood, listening for hollow spaces where grubs hide. When it finds one, it gnaws through the wood with those powerful teeth and uses that skeletal finger to

fish out the grub. The aye-aye has an exceptionally large brain for a prosimian, which it fuels with a protein-rich diet that includes bird eggs and other animal matter. Based on genetic and physical evidence, scientists believe aye-ayes were the first lemurs to branch off from all other prosimians after arriving in Madagascar.



Figure 8.2.6: Aye-aye at night in the wild in Madagascar, image by Frank Vassen, CC BY 2.0 via Wikimedia Commons.

Lemurs also show remarkable diversity in social behavior. Some are solitary foragers who spend most of their time alone. Others live in pairs, some in small groups, others in larger groups, and a few species like the red-ruffed lemur have unique and complex social structures. Many lemurs are among the best vertical clingers and leapers in the primate world, and even the quadrupedal (four-footed) species are impressive jumpers.



Figure 8.2.7: Red ruffed lemurs grooming. Image by Mathias Appel, CC0, via Wikimedia Commons.

Ring-Tailed Lemurs: The Stink Fight Champions

Ring-tailed lemurs (think King Julien from the DreamWorks animated film *Madagascar*) are among the most striking lemurs, recognizable by their vivid yellow eyes and long, eye-catching banded black-and-white tails. Like most prosimians, ring-tails rely heavily on scent—a trait they have turned to their advantage in a uniquely theatrical way: The Stink Fight. This scent-based ritual allows males to compete for access to females without the risk of injury.



Figure 8.2.8: Ring-tailed lemur. Image by Mathias Appel, CC0, via Wikimedia Commons.

Males have scent glands on their wrists that produce a pungent, but short-lived odor, and additional glands on their shoulders that produce a longer-lasting substance. A stink fight begins when two rival males pull their tails through both sets of glands, then wave or flick their scented tails at each other until one backs down. These standoffs can resolve quickly or drag on for up to an hour.

Stink fights tend to peak during mating season and serve a dual purpose: fending off rival males and attracting females through scent-wafting displays that primatologists have dubbed “stink-flirting.” A male’s scent carries detailed information about his genetics and breeding fitness, helping females evaluate potential mates and possibly helping males avoid conflict with close relatives, reducing the risk of inbreeding.



Figure 8.2.9: Ring tail lemur “stink flirting.” Image by Onkel Ramirez from Pixabay.

Other lemur species also use scent to attract mates or intimidate rivals, but the tail-waving stink fight remains a ring-tail lemur specialty, likely shaped by their status as one of the most terrestrial and socially complex lemurs. Those iconic tails are far more than decorative—they’re precision engineered scent delivery systems.

Sources: Duke Lemur Center; Norris, 2012; University of Toronto, 2017.

Lorises, Pottos, and Galagos of Asia and Africa: Life with Competition

While lemurs thrived in isolation on Madagascar, the mainland prosimians faced a very different challenge: competition. Lorises live across South and Southeast Asia, while pottos and galagos inhabit Central Africa. In these regions, they share their environments with monkeys and apes that often eat the same foods. Competition from larger-bodied primates has limited the ecological niches available to them, making them less diverse than their lemur cousins. All of the prosimians in Africa and Asia are nocturnal and solitary, with relatively little variation in body size and diet. They eat mostly fruits and insects, with a few species

consuming more gum, but overall their dietary range is narrow compared to the wider variety seen in lemurs.



Figure $8.2.10a-b$: Nocturnal, solitary lorises. From left: a) The slender loris, image by Kalyan Varma (Kalyanvarma), CC BY-SA 4.0 via Wikimedia Commons; b) Slow loris, image by by Jmiksanek, CC BY-SA 3.0 via Wikimedia Commons.

To help them avoid attracting predators, lorises and pottos have adopted a "stealth mode" lifestyle—they're slow, quadrupedal climbers who move quietly through the forests. But they've also evolved some clever defenses. Lorises, for instance, eat large quantities of caterpillars, which makes their saliva mildly toxic. Loris mothers actually bathe their babies in this toxic saliva, making the infants taste terrible to potential predators, a form of chemical protection that's quite rare among primates.

In stark contrast to the slow-motion lorises and pottos, the galagos are energetic quadrupedal runners and leapers that scurry through the forest canopy at night. They're known for their distinctive vocalizations that sound remarkably like a human baby crying, which earned them the popular nickname "bushbabies."



Figure $8.2.11$: The galago (bushbaby), image by Mark Dumont, CC BY 2.0 via Wikimedia Commons.

Figure 8.2.12 summarizes the key differences between these two groups of prosimians.

	Lemurs	Lorises, Pottos, and Galagos
Geographic Range	Madagascar	South and Southeast Asia, Central Africa
Activity Patterns	Diurnal and/or nocturnal	Nocturnal
Dietary Types	Insectivore, frugivore, or folivore	Insectivore, frugivore
Social groupings	Solitary, pairs, or small to large groups	Solitary
Forms of Locomotion	Vertical clinger leapers, quadrupedal	Slow quadrupedal climbers and active quadrupedal runners and leapers

Figure 8.2.12: Prosimians at a glance: This table summarizes the key differences between the two groups of strepsirrhine (prosimian) primates. Credit: Strepsirrhines at a glance table (Figure 5.19) original to Explorations: An Open Invitation to

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8.3: The Anthropoid Suborder

General Anthropoid Features

When the two primate suborders split from one another, prosimians retained more **ancestral traits** while anthropoids developed more **derived traits**, which are discussed below. As mentioned earlier, anthropoids have better vision than prosimians and therefore have more protection for their eyes, as demonstrated by full postorbital closure protecting the more convergent eyes that anthropoids possess (with one exception as seen in Figure 8.3.1.3).

Most anthropoids are trichromatic, and all have a **fovea**, a depression in the retina at the back of the eye containing concentrations of cells that allows them to see things very close up in great detail. The heavier reliance on vision over olfaction is also reflected in the shorter snouts ending with the dry nose of *haplorrhine* primates, the scientific name for the anthropoids. The vast majority of these primates are **diurnal**—active during the day, so this group lacks the **tapetum lucidum** that is so useful to nocturnal species. On average, anthropoids also have larger brains relative to their body size when compared with prosimians.

The Anthropoids differ from the Prosimians in their ecology and behavior as well. Anthropoids are generally larger and they tend to be leaf and fruit eaters. This dietary difference is reflected in their teeth, which are broader with more surface area for chewing. The larger body size of this taxon also influences locomotion. Only one species is a vertical clinger and leaper. Most members of this suborder are quadrupedal, with one subgroup specialized for **brachiation**.

A few anthropoid taxa are **monomorphic**, meaning males and females are the same size, but many members of this group show moderate to high **sexual dimorphism** in body size and canine size. Anthropoids also differ in social behavior. All but two species live in groups, which is very different from the primarily solitary prosimians. Differences between the two suborders are summarized below.

	Prosimian Suborder (*Strepsirrhini*)	**Anthropoid Suborder (*Haplorrhini*)**
Sensory adaptations	Rhinarium, Longer snout, Eyes less convergent, Postorbital bar, Tapetum lucidim, Mobile ears	No rhinarium, Short snout, Eyes more convergent, Full postorbital closure, No tapetum lucidim, Many are trichromatic, Fovea
Dietary differences	Mostly insectivores or frugivores, few folivores	Few insectivores, mostly frugivores and folivores
Activity patterns and Ecology	Mostly nocturnal, but many diurnal on Madagascar; almost entirely arboreal	Nearly all are diurnal; Arboreal and terrestrial
Social groupings	Mostly solitary, some pairs, or small to large groups on Madagascar	Vast majority live in pairs or small to very large groups
Sexual Dimorphism	Minimal to none	Some taxa have little/none, many taxa show moderate to high dimorphism

The Anthropoid is divided into three infraorders: *Tarsiiformes*, which includes the tarsiers of Asia; *Platyrrhini* (New World monkeys), which includes the monkeys of Central and South America; and *Catarrhini* (Old World monkeys), a group that includes the monkeys of Asia and Africa, apes, and humans. According to molecular estimates, tarsiers split from the other anthropoid primates close to 70 million years ago, and *platyrrhines* split from *catarrhines* close to 46 million years ago (Pozzi et al. 2014).

A note about terminology: The terms “Old World” monkeys and “New World” monkeys come from a colonial worldview. “Old World” referred to Europe, Asia and Africa, while “New World” referred to the Americas as seen through the eyes of European colonizers. Most primatologists today consider these terms outdated and rooted in colonialism. Even so, they remain useful shorthand because they highlight both the distinct evolutionary histories and geographic ranges of these two groups. For that reason, we’ll continue using them throughout the text, but will also include references to their scientific, taxonomic names.

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8.3.1: The Tarsier Infraorder

Meet the Tarsiers

Today, the Infraorder *Tarsiiformes* includes only one genus, *Tarsius*. Tarsiers are small-bodied primates that live in Southeast Asian forests and possess an unusual collection of traits: some like the prosimians, some like the anthropoids, and some that are unique.



Figure 8.3.1.1: Tarsiers are the only living representatives of this Infraorder. Credit: Tarsier Sanctuary, Corella, Bohol (2052878890) by yeowatzup is under a CC BY 2.0 License.



Figure 8.3.1.2: Tarsiiformes are found in the tropical forests of multiple islands in Southeast Asia including Sumatra, Borneo, Celebes, and the Philippines. Credit: Infraorder Tarsiiformes of Asia map (Figure 5.22) original to Explorations: An Open Invitation to Biological Anthropology by Elyssa Ebding at GeoPlace, California State University, Chico is under a CC BY-NC 4.0 License.

Prosimian-like traits

For instance, tarsiers are the only anthropoid primate that are specialized vertical clinger leapers, a form of locomotion only otherwise seen only in prosimians. Tarsiers actually get their name because their ankle (tarsal) bones are elongated to provide a

lever for vertical clinging and leaping. Tarsiers are also very small. Like prosimians, tarsiers are nocturnal, but because they lack a **tapetum lucidum**, tarsiers need to compensate by having enormous eyes. In fact, each eye of a tarsier is larger than its brain. These large eyes allow enough light in for tarsiers to still be able to see well at night without the reflecting layer in their eyes. To protect their large eyes, tarsiers have a partially closed postorbital plate.



Figure 8.3.1.3: Skull of a tarsier showing very large eye sockets and partially closed postorbital plates. Credit: Tarsier skull by Andrew Bardwell is under a CC BY-SA 2.0 License.

Anthropoid-like traits

Despite their overall prosimian-like appearance and behavior, the tarsiers do exhibit some anthropoid adaptations including dry noses, a fovea, not having a *tapetum lucidum*, and eyes that are more convergent. Some species live in small family groups that will cooperate to drive off a predator in their territory.

Tarsiers have different dental formulas on their upper and lower teeth. On the top, the dental formula is 2:1:3:3, but on the bottom it is 1:1:3:3. Other unusual traits of tarsiers include having two grooming claws on each foot and the ability to rotate their heads around 180 degrees in each direction, a trait useful in locating insect prey.

The tarsier diet is considered **carnivorous** because it consists entirely of animal matter, making them the only primate not to eat any vegetation. They are only one of two living anthropoid primates to be solitary, the other being the orangutan. Most tarsiers are not sexually dimorphic, like prosimians, although males of a few species are slightly larger than females.

The table below summarizes the unusual mix of traits seen in tarsiers.

Like Prosimians (*Strepsirrhini*)	Unique	Like Anthropoids (*Haplorrhini*)
Small bodied	Two grooming claws	Almost full post-orbital closure
Nocturnal	2:1:3:3 / 1:1:3:3 dental formula	More convergent eyes
Highly insectivorous	Carnivorous	No tapetum lucidim
Vertical clinger-leapers	Can rotate head nearly 180 degrees	Dry nose (no rhinarium)
Little/no sexual dimorphism		Fovea
		Family groups

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8.3.2: New World Monkeys

The *Platyrrhine* Infaorder

New World Monkeys are the only nonhuman primates found in Central and South America. Like the lemurs of Madagascar, they evolved in relative isolation without competition from other primates, and diversified into a wide range of species as a result. Their scientific name, *Platyrrhini,* actually describes one of their most recognizable features: their noses. "*Platy*" means flat and "*rhini*" refers to nose, and *platyrrhines* do indeed have broad, flat noses with widely spaced nostrils that point outward and are usually round in shape in**.** If you ever need a quick way to tell a New World monkey from an Old World monkey, just look at the nose (Figure 8.3.2.1)



Figure 8.3.2.1: Comparison of New World and Old World monkey noses. From left: A capuchin monkey exhibiting the typical *platyrrhine* nose shape with round nostrils pointing outward on a flat nose. Capuchin Image credit: CARABLANCA – panoramio by Manuel Velazquez, CC BY 3.0 License. Wolf's Guenon (right), an Old World Monkey (*catarrhine*), image by Tim Sackton from Somerville, MA, CC BY-SA 2.0, via Wikimedia Commons



Figure 8.3.2.2: Geographic distribution of the platyrrhines across the southern part of Central America and the tropical and temperate regions of South America. Credit: Infraorder Platyrrhini map original to Explorations: An Open Invitation to Biological Anthropology by Elyssa Ebding at GeoPlace, California State University, Chico is under a CC BY-NC 4.0 License.

Size, Lifestyle, and Vision

Compared to Old World monkeys, New World monkeys tend to be smaller and show less size difference between males and females. They are almost entirely tree-dwellers, while many Old World monkeys regularly come down to the ground.

One of the more interesting differences involves color vision and some key genes related to it. In most New World monkeys, the genes for color vision are carried on the X chromosome. Because males have only one X chromosome, they are limited to seeing just two colors (**dichromatic**). Females, who have two X chromosomes, might see two colors or three depending on whether they carry two different versions of the color vision gene. This makes color vision a bit of a lottery in female New World monkeys.

There are two notable exceptions to this pattern. Owl monkeys, which are nocturnal, have lost color vision entirely and see only in shades of gray (**monochromatic**). Howler monkeys, on the other hand, went the other direction—they evolved to carry two color vision genes on each X chromosome, meaning both males and females can see reds and yellows, which is actually the norm for all Old World monkeys, apes, and humans.



Figure $8.3.2.3a - b$: Different adaptations in vision – the monochromatic owl monkey and the trichromatic howler monkeys. From left: a) Panamanian night (owl) monkeys, image by birdphotos.com, CC BY 3.0, via Wikimedia Commons; and b) Howler monkeys, image by Peter Schoen, CC BY-SA 2.0, via Wikimedia Commons.

The Tiniest Monkeys: Marmosets and Tamarins

At the small end of the size spectrum are the marmosets and tamarins (Figure 8.3.2.4), which weigh less than most house cats. These tiny monkeys live in tight-knit family groups where typically only one female reproduces, and every other member of the group pitches in to carry and raise the young. Unlike most primates, they regularly give birth to twins.

Marmosets and tamarins have an unusual diet, specializing in the gums and saps of trees, a feeding strategy known as gummivory. To pull this off, their bodies have evolved accordingly: they have claw-like nails for clinging vertically to tree trunks (more like a squirrel than a monkey) and specially shaped teeth for gouging through bark to reach the sap beneath. Most species also have one fewer molar than other New World monkeys, giving them a dental formula of 2:1:3:2. Marmoset families defend their favorite feeding trees fiercely, using scent marking to advertise ownership and warn neighboring groups to keep their distance.



Figure 8.3.2.4$a-c$: The smallest monkeys. From left: a) Common marmoset (*Callithrix jacchus*) by Jan Ebr, CC BY-SA 4.0 via Wikimedia Commons; b) Golden lion tamarin (*Leontopithecus rosalia*) in Brazil by Henrique Bitencourt, CC BY-SA 4.0 via Wikimedia Commons; c) Cotton-top tamarin (*Sanguinas oedipus*) by skepticalview is licensed under CC BY-NC-ND 2.0

Nosy Neighbors

Relying on others for help in raising the young means evaluating the help to determine who is or isn't good at cooperation. To do this, common marmosets (*Callithrix jacchus*) actively spy on their neighbors, and new research shows they understand what they overhear. Researchers from the University of Zurich found that these small monkeys listen in on the vocal exchanges of neighboring groups and make social judgments based on what they hear, preferring to interact with individuals they assess as cooperative over those that sound aggressive (Brügger et al., 2021; Joosse, 2021).



Figure 8.3.2.5: Common marmoset mother with babies. Image by Paulo H. Alves, CC BY-SA 4.0 via Wikimedia Commons.

What makes this study especially clever is how researchers detected it. Rather than relying on visible behavioral cues, they used thermal imaging cameras to measure tiny temperature changes in the marmosets' faces while playing back recorded marmoset conversations. When the monkeys heard two individuals interacting, their emotional response—as measured by nasal temperature change—was stronger than when they heard the same calls played separately, suggesting they were processing the exchange as a conversation, not just noise.

The territorial angle is particularly interesting. Female marmosets showed the strongest responses when listening to males interacting with infants from a neighboring group. This signals that a rival family nearby has young offspring, meaning competing females are in the area.

In other words, these tiny monkeys are doing something rather sophisticated: gathering social intelligence about their neighbors before deciding how to respond to them. Knowing your enemy or potential ally appears to be just as important for marmosets as it is for us.

Sources: Brügger, et. al., 2021; Joosse, 2021.

The Big Ones: Spider Monkeys, Woolly Monkeys, and Howlers



Figure $8.3.2.6a-c$: Typical New World Monkeys. From left: a) Central American Spider Monkey, image by Attila Oláh, CC BY 4.0, via Wikimedia Commons; b) Woolly Monkey, image by © Hans Hillewaert via Wikimedia Commons; c) Black Howler Monkey, image by Michael Klotz is licensed under CC BY-NC 2.0.

On the larger end of the spectrum, both in size and in diversity, is the group that includes spider monkeys, woolly monkeys, and howler monkeys (Figure 8.2.3.6a-c). These monkeys have **prehensile tails** that are strong enough to support their entire body weight—essentially, a fifth limb. This gives them an advantage when navigating the treetops and reaching food at the tips of branches.

Spider monkeys are the arboreal acrobats of this group, **semi-brachiators** that swing through the trees using their arms and prehensile tail with amazing speed and agility. This adaptation came with an evolutionary trade-off: spider monkeys have lost their thumbs entirely. Their hands function more like hooks, allowing them to swing swiftly and release branches quickly. Losing a digit, it turns out, made them better at what they do and serves as a useful reminder that natural selection is as much about loss as it is about gain.

As their name suggests, Howler monkeys are famous for their calls, which can be heard several miles away. They achieve this with specialized vocal anatomy that includes an enlarged larynx and hyoid bone. Howlers also hold the title of the most leaf-eating (**folivorous**) among New World monkeys, and they spend a major portion of their day simply resting and digesting in the tree tops.

The Rest of the Group



Figure $8.3.2.7a-d$: More plathyrrhine monkeys. From left a) Capuchin monkeys, image by Carlos Luna is licensed under CC BY 2.0; b) Squirrel monkey, image by London looks, CC BY 2.0 via Wikimedia Commons; c) Red Titi Monkey, image by Steve Wilson - over 6 million views Thanks !! from Chester, UK, CC BY 2.0 via Wikimedia Commons; d) Saki monkey, image by Paul Harrop, CC BY-SA 2.0 via Wikimedia Commons.

The *platyrrhine*s don't stop there. Capuchins are highly social and are among the most tool-savvy of all monkeys, famously observed cracking nuts with stones in the wild—a multi-step, multi-day process that takes planning, patience, and years of practice. Squirrel monkeys form some of the largest social groups of any primate, sometimes in the hundreds. Titi monkeys stand out for being pair-bonded, living as monogamous couples who can often be found sitting side by side with their tails intertwined. While Owl monkeys are the only truly nocturnal monkeys in the world. Saki monkeys and uakaris round out the group, both specializing in cracking open hard seeds that other species cannot access.

Across much of Central and South America, several *platyrrhine* species share the same forests and can even be found traveling together in mixed-species groups, perhaps helping them to collectively spot predators. Based on molecular evidence, the amazing diversity of New World monkeys we see today appears to have originated around 25 million years ago (Schneider and Sampaio, 2015).

Figure 8.2.3.8 below is a summary of how *platyrrhine*s compare to the other major primate groups in terms of key traits.

Platyrrhini Traits

1. Flat nose with rounded nostrils
2. Highly arboreal
3. Less sexually dimorphic on average
4. 2:1:3:3 dental formula*
5. Polymorphic color vision*

Figure 8.2.3.8: Platyrrhini at a glance: Summary of the key traits we use to distinguish platyrrhines. Traits indicated with an * are those with exceptions detailed in the text. Credit: Platyrrhini at a glance table (Figure 5.29) original to Explorations: An Open Invitation to Biological Anthropology by Stephanie Etting is under a CC BY-NC 4.0 License.

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8.3.3: Old World Monkeys

The *Catarrhine* Infraorder

Based on genetic evidence, around 32 million years ago, one lineage of primates split into two groups that would eventually become very familiar: the monkeys of Africa and Asia on one side, and apes and humans on the other. The fossil record backs this up, with evidence of both lineages appearing by about 25 million years ago (Schneider and Sampaio 2015). Today we call these two groups Superfamily *Cercopithecoidea* (the Old World monkeys) and Superfamily *Hominoidea* (the apes and humans), and together they make up the *catarrhine*s.

So just how many Old World monkey species are there? It depends on who you ask. Estimates range from around 132 to 138 species depending on the classification system used, and that number continues to change as genetic studies reveal new distinctions between populations once considered the same species. This is a good reminder that taxonomy is not a finished product—it is an active, ongoing scientific conversation, and primatology is right in the middle of it. What we can say with confidence is that Old World monkeys are the largest primate family on the planet, with at least 24 genera spread across Africa and South and Southeast Asia.

What Makes an Old World Monkey?

As you've learned, the nose is the quickest giveaway when it comes to telling Old World and New World monkeys apart. Old World monkeys have teardrop-shaped nostrils set close together and pointing downward, a feature so distinctive that scientists use it to define the entire group. The term "catarrhine" comes from the Greek for "downward nose."



Figure 8.3.3.1: A Red Crowned Mangabey monkey exhibiting *catarrhine* nose features, image by Keven Law, CC BY-SA 2 via Wikimedia Commons.



Figure 8.3.3.2: A male Mandrill with bright coloration which signals quality of health to females. Image by Paolo Camera, CC BY 2.0 via Wikimedia Commons.

Old World monkeys tend to be larger and more sexually dimorphic than their New World counterparts. In fact, *catarrhine*s include the most sexually dimorphic of all primates: the mandrill. Male mandrills not only outweigh females by up to three times, they also sport dramatically more vivid coloration and larger canines, making the difference between the sexes almost impossible to miss.

Old World monkeys also have one fewer premolar than most other primates, giving them a dental formula of 2:1:2:3.

One more trait sets *catarrhine*s apart: color vision. Like howler monkeys, all *catarrhine*s independently evolved the ability to distinguish reds and yellows from blues and greens, making both males and females **trichromatic**. For animals that are active during the day and depend on finding ripe fruit, this is a significant advantage.

Built Like Monkeys, Not Like Apes

Compared to apes, Old World monkeys have retained a more ancestral four-limbed, or **quadrupedal**, body plan. But they have also evolved two distinctive traits of their own that set them apart from all other primates.

The first is their **bilophodont** molars. That's a mouthful but it can be broken down: "**bi**" means two, "**loph**" means ridge, and "**dont**" means tooth. Looking at Figure 8.3.3, you can make out this pattern. The molars of Old World monkeys have four cusps arranged in a square, connected by two parallel ridges. This tooth shape turns out to be very versatile, allowing Old World monkeys to process a wide range of foods. Many researchers believe this dietary flexibility is a big part of why Old World monkeys have been able to colonize such a broad range of habitats, including drier, more seasonal environments where apes simply cannot survive.

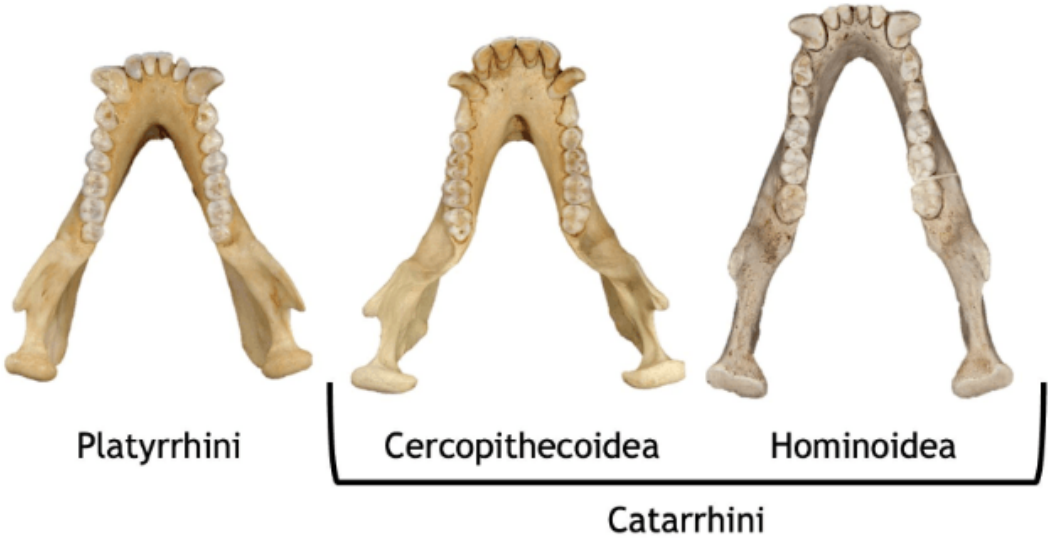


Figure 8.3.3.3: *Catarrhine*s have two premolars whereas most other primate taxa (including platyrrhini) have three premolars. This image also shows one of the derived traits of cercopithecoids, their bilophodont molars, which differ from the more ancestral Y-5 molars of apes and humans.

Credit: Platyrrhini vs. Catarrhini dentition original to Explorations: An Open Invitation to Biological Anthropology by Stephanie Etting is a collective work under a CC BY-NC-SA 4.0 License. [Includes Cebus apella (brown capuchin) at Animal Diversity Web by Phil Myers, CC BY-NC-SA 3.0; Lophocebus albigena (gray-cheeked mangaby) at Animal Diversity Web by Phil Myers, CC BY-NC-SA 3.0; Symphalangus syndactylus (siamang) at Animal Diversity Web by Phil Myers, CC BY-NC-SA 3.0.]

The second distinctive trait is something you can actually relate to right now: **ischial callosities**. The ischium is the part of your pelvis you are sitting on as you read this. In Old World monkeys, this same region of the pelvis has a flattened surface covered by thick, callused skin. Think of them as built-in seat cushions. Since Old World monkeys spend a lot of time sitting on branches while feeding and resting, these *callosities* are a practical adaptation for life spent seated in an upright, vertical position in the trees.

The Most Successful Monkeys on Earth

Old World monkeys are the most geographically widespread group of nonhuman primates on earth, ranging from the rainforests of West Africa to the snowy mountains of Japan. A big part of their success comes down to reproduction. On average, Old World monkeys reproduce every one to two years, compared to once every four to nine years for apes. That faster reproductive rate has allowed *cercopithecoid* populations to grow and diversify far more rapidly than their *hominoid* relatives, helping them spread into an expansive range of habitats.

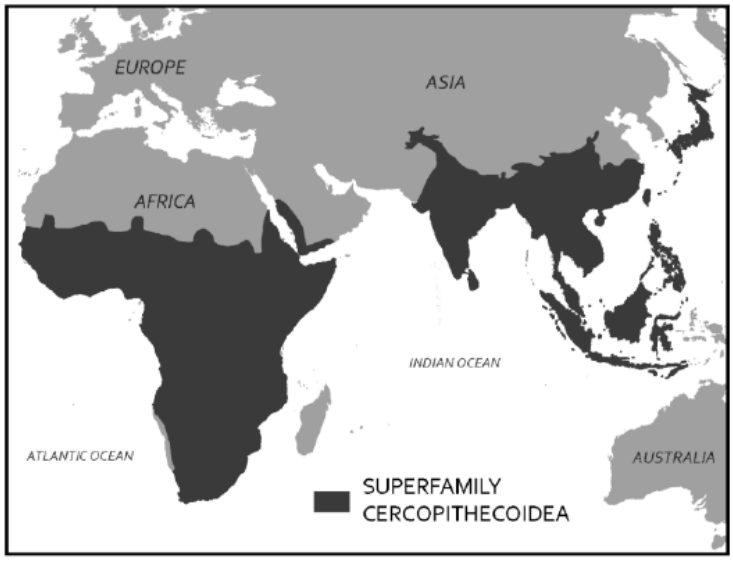


Figure 8.3.3.4: Geographic distribution of the cercopithecoid monkeys. Catarrhines have the widest geographic distribution due to the success of cercopithecoids who are found all across subsaharan Africa and southern Asia. Credit: Superfamily Cercopithecoidea map (Figure 5.33) original to Explorations: An Open Invitation to Biological Anthropology by Elyssa Ebding at GeoPlace, California State University, Chico is under a CC BY-NC 4.0 License.

Two Groups: Leaf Monkeys and Cheek-Pouch Monkeys

Old World monkeys are divided into two main groups whose names give you a pretty good hint about how they live. The leaf monkeys, or *colobines*, are primarily **folivores** (leaf eaters) though some species also eat significant amounts of seeds. The cheek-pouch monkeys, or *cercopithecines*, tend to be more frugivorous or omnivorous.

Both groups are found across Africa and Asia, though their distributions differ. The majority of leaf monkey species live in Asia, with only a few found in Africa. Cheek-pouch monkeys show the opposite pattern—only one genus lives in Asia, while the rest are found across Africa.

The two groups also differ in some visually striking ways. Leaf monkey infants are often born with fur that is a completely different color from their parents, making them immediately recognizable within the group.



Figure 8.3.3.5: Silver leaf monkey infants are born with orange fur, dramatically contrasting the adult coat color of their mothers. After a few months, the infants gradually change color to that of their parents. Credit: Peter Gronemann from Switzerland, CC BY 2.0, via Wikimedia Commons

Many leaf monkey species are also known for their distinctively unusual noses, earning them the nickname "odd-nosed monkeys." Perhaps the most immediately recognizable *colobine* is the proboscis monkey (*Nasalis larvatus*) of Borneo, where males develop an extraordinary pendulous nose that can reach up to 10 centimeters in length. Females have much smaller, upturned noses by comparison, making this one of the most striking examples of sexual dimorphism in the primate world. The function of the male's oversized nose is thought to be related to mate attraction, as it amplifies vocalizations and may signal overall health and genetic quality to females. Proboscis monkeys are now endangered, threatened by the same forces driving declines across Southeast Asia: deforestation, habitat conversion, and hunting.

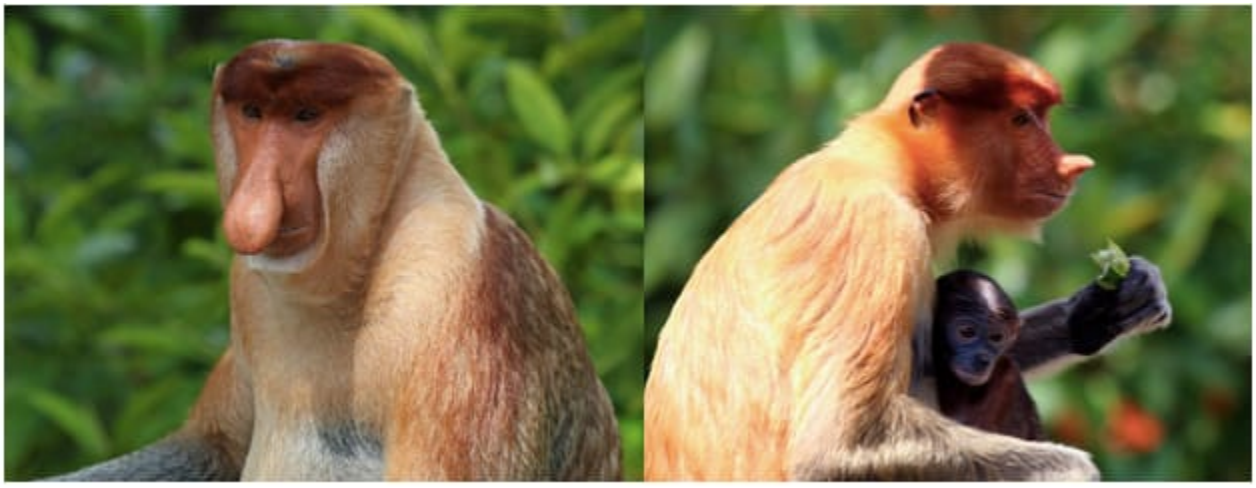


Figure 8.3.3.6$a-b$: Proboscis monkeys are one of several “odd-nosed” leaf monkeys. a) Male proboscis monkeys, like this one, have large, pendulous noses. B) Females have a smaller, upturned nose (note the different coat color of the baby). Credit: Proboscis monkey (Nasalis larvatus) male head and Female and baby by Charles J Sharp is under a CC BY-SA 4.0 License.



Figure 8.3.3.7: This bonnet macaque has filled its cheek pouches with food, an adaptation that is useful in transporting food to a safer location to eat. Credit: Bonnet macaque DSC 0893 by T. R. Shankar Raman is under a CC BY-SA 4.0 License.

Cheek-pouch monkeys, meanwhile, have evolved a clever survival strategy: expandable cheek pouches that allow them to rapidly stuff food into their mouths and then retreat to a safe location away from predators or aggressive group members to eat at their leisure.

The monkeys of the Old World represent one of the most successful primate radiations on earth. This section has covered only a fraction of these striking, versatile, and fascinating species, but it has helped set the stage for understanding the lineage that branched off from them and eventually gave rise to the apes, and ultimately, our own lineage.

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8.3.4: The Apes

Superfamily *Hominoidea*

All apes live in Africa or southern Asia. Compared to monkeys, apes are larger-bodied, larger-brained, and most are adapted for spending time on the ground. One of the easiest ways to tell an ape from a monkey is by the absence of a tail.

Apes are divided into two main groups: the small-bodied apes — gibbons and siamangs — and the large-bodied apes — gorillas, chimpanzees, bonobos, and orangutans. Humans are also classified within this group, making us hominoids too.

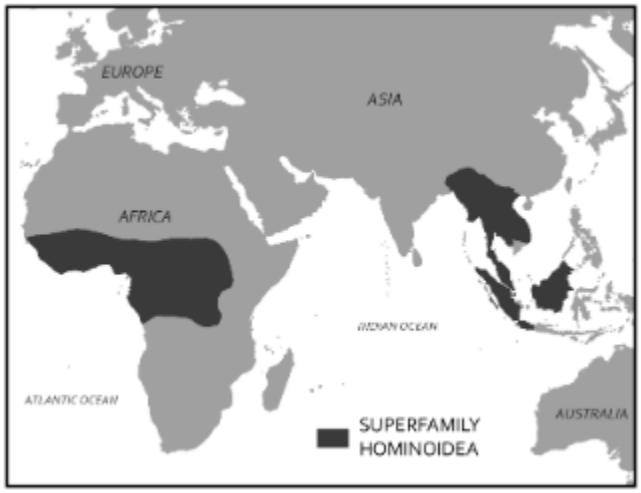


Figure 8.3.4.1: Geographic distribution of apes across Central and West Africa and Southeast Asia. Hominoids overlap geographically with cercopithecoid monkeys but have a lower tolerance for seasonal environments and so are found only in tropical forests across these regions. Credit: Superfamily Hominoidea map (Figure 5.38) original to Explorations: An Open Invitation to Biological Anthropology by Elyssa Ebding at GeoPlace, California State University, Chico is under a CC BY-NC 4.0 License.

Built for Swinging: The Ape Body Plan

What really sets apes apart from other primates is how their bodies are built for **brachiation**—swinging below branches using their arms. This form of locomotion has shaped some important features of ape anatomy. To maximize reach, ape arms are much longer than their legs. Their torsos are broader and more upright than those of monkeys, and their shoulders and arms in particular have a much wider range of motion and flexibility. The collarbone (clavicle) is longer than in other primates, which stabilizes the shoulder joint and allows apes to rotate their arms a full 360 degrees, making them the best adapted primates on the “monkey” bars.

Distinctive Molars

Another feature that sets apes apart is their **Y-5 molar pattern**. If you look at an ape molar, you’ll find five cusps arranged with a groove between them that forms a “Y” shape. This pattern was also present in the common ancestors of apes and Old World monkeys, making it a useful trait for tracing evolutionary history.

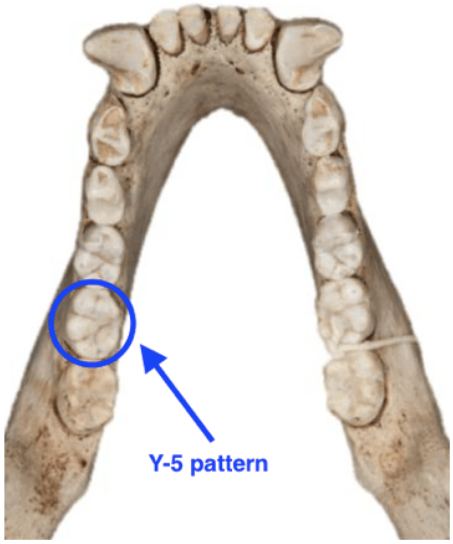


Figure 8.3.4.2: The Y-5 molar pattern found in apes and humans. Credit: Platyrrhini vs. Catarrhini dentition original to Explorations: An Open Invitation to Biological Anthropology by Stephanie Etting is a collective work under a CC BY-NC-SA 4.0 License.

Slow to Grow, Slow to Reproduce

As hominoids, apes and humans share another distinction: we have the longest life histories of any primates. Apes take a long time to reach adulthood, and females reproduce far less frequently than monkeys do, often raising one offspring at a time over many years. This slow reproductive rate, combined with habitat loss, hunting pressure, and poaching, is a big part of why apes are among the most endangered animals on the planet. It also helps explain why, despite being around for millions of years, there are relatively few ape species compared to monkeys.

In the sections that follow, you'll be introduced to the six types of non-human apes that still share the planet with us. Only one hominoid is a serious threat to all the rest: us. As you get to know our closest living relatives in the pages ahead, it will become clear that their fate, like so much of the natural world, rests largely in human hands.

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8.3.4.1: Gibbons and Siamangs

The Acrobats of the Forest

These small-bodied apes are the daring acrobats of Southeast Asian tropical forests. They spend nearly all of their time in the trees, swinging from branch to branch with their long, powerful arms and hook-like hands — including moments of pure free-flight — moving swiftly through the canopy. Occasionally they run along the tops of branches on two feet, holding their long arms overhead for balance. They are the most skilled brachiators of all primates.

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

National Geographic (2007, September 4). *The Swinging Gibbon | National Geographic*. [Video]. YouTube. https://youtu.be/mSLFHPd8LX0?si=y0bnTwM3CWZgBqiV

Despite living almost entirely in the trees, gibbons and siamangs don't build sleeping nests the way the great apes do. They simply find a branch and settle in for night.

Gibbons come in a range of colors and markings depending on the species, while siamangs are uniformly black and sport large throat sacs that amplify their calls across the forest. Both gibbons and siamangs live in monogamous pairs and show very little size difference between males and females, though in some gibbon species the sexes differ in coloration.



Figure 8.3.4.1.1:Siamangs are the largest of the Hylobatidae family. They are all black with a throat sac that can become inflated to give out loud calls. Credit: Shout (3733107729) by su neko is under a CC BY-SA 2.0 License.

Singers of the Forest

Gibbons are among the most vocal of all primates. Known as the "singers of the forest," they use their calls to defend territory and reinforce the bond between mated pairs. Every morning, gibbon families perform a chorus that can last up to 15 minutes and carry nearly 2 kilometers through the forest. In some species, only the male sings. In others, mated pairs perform duets, sometimes joined by their offspring. The longer a pair has been together, the more synchronized and polished their duet becomes. When the morning chorus is done, the family heads out to forage, led by the female.

Although they are highly territorial, gibbons and siamangs usually avoid actual physical altercations over their home turf. Instead, they rely on an impressive toolkit of theatrics: acrobatic displays, branch-breaking, chasing, and of course, more loud calling. These constant vocalizations also help neighboring groups stay spaced out in the dense canopy and avoid unexpected run-ins.



Figure 8.3.4.1.2: Male and female gibbon pair. Image by User:MatthiasKabel, CC BY-SA 3.0 via Wikimedia Commons

Gibbon Ecology

Gibbons are **frugivores**. While fruit makes up the largest portion of their diet, they also eat leaves, flowers, and insects to round things out. Their small body size is a real advantage here, allowing them to venture out to the thin, fruit-bearing tips of branches where heavier animals simply can't go. You might spot one hanging from a branch by one hand while plucking fruit and popping it into its mouth with the other.

What gibbons take from the forest, they also give back. Studies of gibbon ecology show that they are important seed-dispersers. One study in Borneo found that gibbons disperse seeds from 81% of the plant species they eat and many of those seeds germinate better after passing through the gibbon's gut. Their fondness for figs is especially significant, since fig trees support thousands of species of insects, birds, and other animals — including people.

It follows that the health of Southeast Asia's biodiverse forests is closely tied to the survival of gibbons. Unfortunately, these remarkable animals are among the most endangered primates on the planet.

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8.3.4.2: Orangutans

The Great Apes of Southeast Asia

Orangutans are the only great apes to live outside of Africa, found exclusively on the islands of Borneo and Sumatra in Indonesia. These large, red-haired apes have a lifestyle quite unlike their African cousins. They are largely solitary with adults spending most of their lives alone. The exception is that of a mother and her dependent young. Despite their large size, orangutans live high in the rainforest canopy, which makes them not only the largest tree-dwelling primate, but the largest arboreal mammal on Earth.

Orangutans are also the slowest-reproducing of all primates. Females don't reach reproductive age until around 12 to 15 years old, and once they do, they give birth to just one baby every 7 to 9 years. Over a lifetime, a female may raise only four or five offspring, which makes every individual critically important to the survival of the species.

What They Eat and How They Live

Orangutans are primarily fruit eaters, but they're opportunistic and adaptable. When fruit is scarce, they supplement their diet with leaves, bark, insects, and bird eggs. They have even been observed extracting honey from beehives. While they do use tools, they don't rely on them as extensively as chimpanzees do.

Like gibbons, orangutans play a vital role as seed dispersers in the rainforest, particularly for plants with large seeds that other animals can't swallow. As they feed high in the canopy, dropping fruit as they go, they inadvertently provide food for ground-dwelling animals below.

Male and female orangutans look strikingly different from one another with males being nearly double the size of females and having distinctive features that include throat sacs, wide flanged cheeks, and long shaggy coats.



Figure $8.3.4.2.1a-b$: a) A female orangutan eating fruit with her infant nearby and b) a flanged adult male eating leaves. Male orangutans are about twice the size of females and have a longer coat length, cheek flanges, and throat sac. Credit: a) Orang Utan (Pongo pygmaeus) female with baby (8066259067) by Bernard DUPONT is under a CC BY-SA 2.0 Licence. b) Orangutan -Zoologischer Garten Berlin-8a by David Forsman is under a CC BY 2.0 License.

A Species in Crisis

Orangutans are critically endangered, and the threats they face are largely human-made. Rapid destruction of their rainforest habitat cleared for logging or converted to agricultural land has caused steep population declines over the last two decades. Palm

oil plantations, many planted on cleared rainforest, have become a particular flashpoint: orangutans sometimes raid the palms for their hearts, and in response are hunted or killed as pests, despite the fact that their forest home was cleared in the first place.

Baby orangutans are also targeted for the illegal pet trade, though few survive long after being taken from the wild. When you combine all of these threats with the slowest reproductive rate of any primate, the stakes become clear: orangutans simply cannot bounce back quickly from population losses. Critically endangered means one step above extinct—and for orangutans, that step is getting smaller.

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8.3.4.3: Gorillas

The Gentle Giants



Figure $8.3.4.3.1a-b$: a) A female gorilla with her two offspring and (b) a silverback adult male. Male gorillas are about twice the size of females. They also differ from females in having a large sagittal crest and a silver back, which appears as they mature. Credit: a. Enzo naomi echo by Zoostar is under a CC BY 3.0 License. b. Male gorilla in SF zoo by Brocken Inaglory is under a CC BY-SA 3.0 License.

If you've ever had the chance to observe gorillas at a zoo, you probably couldn't help but feel struck by their sheer size, their human-like gestures, and their surprisingly gentle nature. They are truly magnificent animals. In fact, gorillas are so calm and approachable, even in the wild, that people pay up to thousands of dollars for guided gorilla treks in central Africa just for the chance to spend anywhere from an hour to half a day in their presence.

That gentle quality has captivated researchers and filmmakers for decades. In a recent Netflix documentary, “A Gorilla Story,” Sir David Attenborough returns to the forests of Rwanda to track down the descendants of a male gorilla, named Pablo, that he first met in the 1970s while filming “Life on Earth” for the BBC. Pablo grew up to become a dominant silverback whose family would come to lead the largest mountain gorilla group ever recorded. The documentary offers a rare multigenerational glimpse into gorilla life and serves as both a celebration of these animals and a sobering reminder of how much their world has changed.

The Dian Fossey Gorilla Fund and the Power of Long Term Research

The recovery of mountain gorillas didn't happen by accident. It is the result of decades of patient, rigorous scientific work, much of it carried out by the Dian Fossey Gorilla Fund. Founded in 1967 by pioneering primatologist Dian Fossey, the organization is now the world's largest and longest-running dedicated to gorilla conservation.

Recently, the Fossey Fund served as scientific advisors on the Netflix documentary *A Gorilla Story: Told by David Attenborough*, providing field expertise and behavioral interpretation drawn from nearly six decades of continuous research. The film follows the remarkable history of the Pablo family of mountain gorillas, a group followed across generations since Fossey's time. Without that deep scientific foundation, the filmmakers could not have told the full and intimate story of a real-life gorilla dynasty.

This is a powerful example of why long-term scientific research matters. Individual studies capture snapshots; decades of continuous observation reveal a richer, fuller picture — births, deaths, power struggles, family bonds, and the slow changes that shape a population over time. The mountain gorillas represent one of conservation’s rare success stories. Once pushed toward extinction, they are now the only great ape species whose population is increasing — a recovery made possible through a sustained commitment to research and collaboration with local communities.

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

Netflix (2026, March 23). *A Gorilla Story: Told by David Attenborough |Official Trailer |Netflix*. [Video]. YouTube. https://youtu.be/u6Qs4W0uwBw?si=DoL8FtQMSlUH3lRZ

About The Dian Fossey Gorilla Fund

Established in 1967 by famed primatologist Dian Fossey, the Fossey Fund works in Rwanda and the Democratic Republic of the Congo to protect and study critically endangered wild gorillas and their habitats, and to support the people who share the gorillas' forest home. For more information, visit: gorillafund.org. Follow them on social @savinggorillas.



Figure 8.3.4.3.2: Primatologist Dian Fossey holding a poster of a gorilla. Tribune Publishing, no photographer credited, Public domain, via Wikimedia Commons.

Size, Social Life, and Structure

Gorillas are the largest of all apes and live exclusively in Africa. They live in social groups called troops, typically made up of 10 to 20 individuals—one dominant silverback male, several adult females, and their offspring. The silverback gets his name from the distinctive patch of silvery hair that develops on his back and rump as he matures. He is the sole breeding male in the group, and his role goes beyond reproduction: he protects the troop, mediates conflicts, and plays an active role in socializing the younger members. This mating arrangement—one male with multiple females—is known as **polygyny**, a pattern seen in some human societies as well.

The size difference between males and females is striking. Males can weigh up to 350-400 pounds, while females typically weigh closer to 155-200 pounds, making gorillas one of the most sexually dimorphic of the great apes.

Daily Life



Figure 8.3.4.3.3: Gorilla munching on bamboo leaves. Image by Magdalena Kula Manchee on Unsplash.

Gorillas are primarily **herbivores**, feeding mainly on leaves, stems, and fruit, occasionally supplemented with ants and other insects. Given the relatively low caloric density of leaves, gorillas spend a large portion of their waking hours eating as it takes a lot of foliage to fuel a 350-pound ape.

They move through their environment by knuckle-walking, supporting their weight on the knuckles of their hands rather than their palms. While they are capable climbers, gorillas are mostly terrestrial and construct sleeping nests on the ground whenever they want to rest or sleep, weaving together nearby leaves, vines, and branches into a comfortable bed. With the exception of young infants, who sleep with their mothers, each gorilla in the troop builds its own nest. And since gorillas follow food availability and are frequently on the move, they rarely sleep in the same spot twice.

Because gorillas can be elusive and shy around humans, field scientists often rely on nest counts to estimate the size and movements of a troop. Each nest represents one individual, making them a surprisingly useful census tool.

Gorilla infants are born helpless and require intensive care from their mothers, nursing at least once an hour in the early weeks of life. Silverbacks also invest in the young of the group—protecting infants from threats and playing an important role in socializing juveniles. In the wild, gorillas typically live between 35 and 40 years.

Two Species, Both in Trouble

Gorillas are divided into two species: the western gorilla and the eastern gorilla. All populations are critically endangered, meaning they are one step away from extinction. Perhaps the most well-known are the mountain gorillas (*Gorilla beringei beringei*), a subspecies of eastern gorilla living in the highland forests of the Democratic Republic of Congo, Rwanda, and Uganda near the Virunga volcanoes. With under 1,000 individuals remaining, their situation is precarious. Threats include poaching, habitat loss due to human expansion, and the destabilizing effects of ongoing political unrest in the region, making conservation work both urgent and dangerous.



Figure 8.3.4.3.4$a-b$: a) Male Western Lowland Gorilla. Image by k7hpn, CC BY 2.0 via Wikimedia Commons; b) Male Mountain Gorilla. Image by Dave Proffer, CC BY 2.0 via Wikimedia Commons.

As discussed in the section above, there is a rare conservation success story here. Mountain gorilla numbers hit an all-time low of just 254 individuals in the 1980s, but sustained conservation efforts have slowly pushed that number back up. They are one of the few great apes whose population is actually growing.

Notably, there are no mountain gorillas in captivity, and this is unlikely to change. Mountain gorillas are highly sensitive to human diseases, including common respiratory illnesses like the cold and flu, to which they have little natural immunity. In captivity, the risk of disease transmission from humans is extremely difficult to control. Mountain gorillas are also deeply tied to their high-altitude forest habitat, which is difficult to replicate in a zoo setting. They have a highly specialized diet of specific plants that grow in those forests, and the psychological stress of captivity itself has proven fatal. Previous attempts to keep mountain gorillas in captivity have resulted in the animals' deaths, and conservationists have concluded that their survival depends entirely on protecting them in the wild.



Figure 8.3.4.3.5: A young gorilla. Image by Bob Brewer on Unsplash.

The picture is darker for the eastern lowland gorilla, whose population has declined by roughly 70% over the last two decades — a staggering loss driven by habitat destruction, instability in the region, and a threat that has grown more calculated and demand-driven over time: the illegal wildlife trade. As discussed in Chapter 7, the trade in baby great apes has evolved into a deliberate, order-driven business fueled in part by social media. Every infant taken represents not just one lost animal, but the loss of a future

mother or silverback, and for a species already in steep decline, those losses compound quickly.

For gorillas, as for all great apes, the threats are interconnected. Forests are cleared, instability follows, hunters move in, and traffickers are not far behind. Understanding these pressures together, rather than in isolation, is essential for understanding why great ape populations are in crisis, and what it will take to turn the tide.

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8.3.4.4: Chimpanzees and Bonobos

Chimpanzees and Bonobos: Our Closest Relatives

Of all the primates, chimpanzees and bonobos tell us the most about our own evolutionary history. There are two species: the common chimpanzee (*Pan troglodytes*) and the bonobo (*Pan paniscus*). Both share approximately 99% of their DNA with humans, which makes them genetically closer to us than they are to gorillas or orangutans. Yet despite their near-identical genetics, these two species have evolved strikingly different societies, and comparing them gives us a fascinating window into the range of social behaviors that may have existed in our shared evolutionary past.



Figure $8.3.4.4.1a-b$: a) Common Chimpanzee (Pan troglodytes). Image by by Wietse Jongsma on Unsplash; b) Bonobo (Pan paniscus). You can see the distinctive hair-part on the bonobo. Credit: Bonobo male Jasongo 15yo Twycross 582a (2014 11 14 01 04 18 UTC) by William H. Calvin is under a CC BY-SA 4.0 License.

Two Species, Two Worlds

Like gorillas, both chimpanzees and bonobos are knuckle-walkers, moving on all fours with their weight supported on their knuckles. Chimpanzees are found across tropical Africa and into savanna environments, while bonobos live exclusively in the dense rainforests of the Democratic Republic of Congo, south of the Congo River — a geographic barrier that has kept the two species separated for roughly one million years. Both species split their time between the ground and the trees.

Chimpanzees and bonobos are less sexually dimorphic than the other great apes, though males are somewhat larger than females. Chimpanzees are primarily fruit eaters but are flexible and opportunistic, eating leaves, eggs, insects, and occasionally meat. Chimpanzees and bonobos are also among the only primates, besides humans, that regularly share food, and they do so for remarkably human-like reasons: to support close relatives, to reinforce friendships, and because defending food from persistent group members is sometimes more trouble than it's worth.

The Political World of Chimps

Chimpanzee society is complex, competitive, and there's really no better word for it — political. Troops can number up to 60 individuals, but chimpanzees typically travel and forage in smaller parties that shift in composition throughout the day. Within the larger community, males form a clear dominance hierarchy, maneuvering for status through dramatic displays such as hooting, jumping, dragging objects, and pounding the ground, all designed to intimidate rivals without necessarily resorting to outright violence.

But theatrics and intimidation only go so far. What really determines a male's success is his alliances. Males form tight coalitions cemented through grooming — literally scratching each other's backs. These friendships are long-lasting, strategic, and critically important. A male with powerful allies can challenge individuals he couldn't dominate alone. Chimpanzees remember favors, hold grudges, and will gang up on a dominant individual who has overstepped.



Figure 8.3.4.4.2: An adult female chimp with her offspring cuddled close. Colorado State University Libraries, CC BY-SA 4.0 via Wikimedia Commons.

Males remain in the community they were born into for life, which is what makes these coalitions possible. Females, by contrast, leave their natal group when they reach sexual maturity and join a new community — a pattern called female dispersal that reduces inbreeding and shapes the genetic structure of chimpanzee populations.

Male chimpanzees also cooperate to patrol and defend their territory. These patrols are silent and deliberate, and when a patrolling group encounters a lone individual from a neighboring community, the encounter can turn violent. Jane Goodall documented one troop systematically killing all the males of a neighboring group that had splintered off — behavior that struck many observers as disturbingly reminiscent of human intergroup conflict.

The Tool Users



Figure 8.3.4.4.3: Chimpanzee holding a stem stripped of leaves, tool-use behavior. Image from Pixabay.

What makes chimpanzee tool use especially interesting is that it varies from population to population. Different communities use different tools in different ways, and young chimps learn by closely watching their mothers. This is not unlike cultural transmission: the passing of learned behaviors across generations, not through genes, but through observation and practice. Of all non-human animals, chimpanzees use tools to solve the greatest range of problems both in the wild and in captivity. And notably, it is female chimpanzees who use tools most frequently. As the primary care providers for their young, they have a compelling reason to be

innovative — to increase the chances of survival of their offspring, and her own reproductive success.

Communication and Reproduction

Chimpanzees communicate through a rich repertoire of vocalizations, from soft grunts to the loud, far-carrying pant-hoot, as well as gestures. One of the most recognizable is the outstretched hand, used to request food or reassurance. Interestingly, while humans point to direct others' attention from an early age, chimpanzees do not naturally point in the wild, though they can learn to do so in captivity.

Female chimps have a visible ovulation cycle called **estrus**, marked by a pronounced pink genital swelling that signals fertility. Males show heightened interest in mating during this period. Male chimpanzees also show a preference for older, more experienced females — a pattern that makes sense given that older females tend to be more competent mothers.

Bonobos: A Different Kind of Ape



Figure 8.3.4.4.4: A bonobo. Image by Evanmaclean, Public domain, via Wikimedia Commons.

Bonobos look remarkably similar to chimpanzees though they are slightly smaller, with darker faces and a more upright posture. It's their social world that makes them strikingly different. Where chimpanzee society is male-dominated and frequently tense, bonobo society is female-led and largely peaceful. Among bonobos, females form strong alliances with one another through grooming and affiliative behaviors, and it's these alliances that give females their social leverage. A male bonobo's status is largely determined by his mother's rank—a striking contrast to the coalition-building and competitive displays that define male chimpanzee hierarchies.



Figure $8.3.4.4.5a - b$: From left: a) Female bonobo with baby. Image by Pierre Fidenci, CC BY-SA 2.5 via Wikimedia Commons; b) Bonobos at the San Diego Zoo grooming. Image by NauticalVoyager, CC0, via Wikimedia Commons.

Perhaps the most distinctive feature of bonobo society is how conflict is managed. Rather than resolving tension through aggression, bonobos use sexual behavior — including non-reproductive contact between individuals of the same and opposite sex — to ease social stress, reconcile after disagreements, and build social bonds. This happens across genders and is a routine part of bonobo social life. Their use of sex in non-reproductive contexts is more extensive than in any other non-human primate, and in some ways more closely parallels human sexual behavior than that of any other species.

The contrast between chimpanzees and bonobos is one of the most thought-provoking puzzles in primatology. Two species, nearly identical in their DNA, living utterly different social lives. Understanding both species while resisting the urge to see either as a “default” model for our ancestors, gives us a far richer picture of what early human social life might have looked like.

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8.3.4.5: Humans

Genus *Homo*

After surveying the extraordinary diversity of primates, you might be wondering: what actually makes humans unique? It's a harder question to answer than you might expect. The more you learn about other primates, the more the boundaries between "us" and "them" begin to blur. Chimpanzees use tools, form political alliances, and grieve their dead. Gorillas are gentle, socially complex, and devoted parents. Bonobos resolve conflict through empathy and affiliation. So where exactly do humans fit in?

That question is one of the driving forces behind biological anthropology, and we'll be exploring it in the next chapter and in more depth in the next unit on hominin evolution. For now, as we wrap up our survey of primate diversity, it's worth pausing to consider not what sets humans apart, but what connects us to the rest of the primate family tree.

More Primate Than We Think

There is only one living species in Genus Homo: *Homo sapiens*. And like every other member of Superfamily *Hominoidea*, we carry the hallmarks of our ape ancestry in our bodies whether we realize it or not.

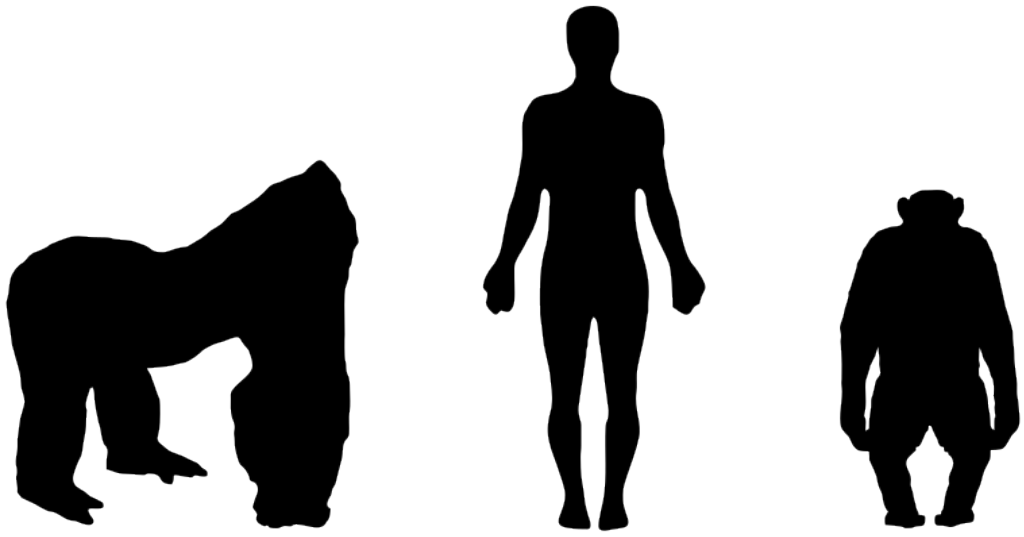


Figure 8.3.4.5.1:Comparison of size of western gorilla (*Gorilla gorilla*), chimpanzee (*Pan troglodytes*) and human. Image by The Nature Box, CC BY-SA 4.0 via Wikimedia Commons.

Like all *hominoids*, humans have no tail. Our upper bodies retain the adaptations for brachiation that evolved in our tree-swinging ancestors. The same mobile shoulder joint that allowed our relatives to swing through the canopy allows us to throw a baseball, reach overhead, and rotate our arms in ways most other mammals cannot. Our molars carry the Y-5 cusp pattern shared by all apes, a dental signature connecting us to a lineage that stretches back millions of years. We also share an extended life history like the other hominoids—we take longer to grow up, reproduce more slowly, and living longer relative to most other mammals. Even the tendency seen in many human societies for women to leave their birth community upon marriage, known as female dispersal, has parallels across other hominoid species (Burton et al. 1996).

Behaviorally, our similarities with chimps and bonobos are striking. Males in all three species cooperate in hunting and territorial defense, and all three use tools (Gibbons 2008). These are all echoes of a shared evolutionary history. Why and how the human lineage diverged so dramatically from our common ancestor is one of the most intriguing questions in all of science, and is where we're headed next.

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8.4: Primate Research- A Complicated History

Our Closest Relatives and a Complicated History

The fact that chimpanzees and bonobos share more than 98% of their DNA with humans has meant that for much of the twentieth century, it made them prime candidates for biomedical research. Their genetic and physiological similarity to humans made them attractive to scientists studying infectious diseases, vaccine development, and drug safety. At their peak, nearly a thousand chimpanzees were held in U.S. research facilities alone.

That era is now largely over. In 2013, the NIH announced a significant reduction in chimpanzee research, and in 2015 it went further, announcing a complete end to funding biomedical research on chimpanzees and declaring all federally owned chimpanzees eligible for retirement to sanctuary. Former NIH Director Dr. Francis Collins announced that NIH would no longer support biomedical research on chimpanzees, and a plan was developed to retire NIH-owned chimpanzees to Chimp Haven, a federal sanctuary in Keithville, Louisiana. As recently as November 2024, NIH reversed a decision to keep government-owned chimpanzees at a New Mexico laboratory for the rest of their lives, instead ordering their relocation to sanctuary (Project R & R, n.d., National Institute of Health, 2025, Block & Admundson, 2024).

The broader question of primate research is still very much in flux. Monkeys continue to be held and used for research purposes in the United States, but there is a movement both within and outside the government to make animal testing the exception rather than the rule. For students of anthropology, this history raises questions that go beyond science. If our genetic closeness to chimps, bonobos, and other primates is what made them so useful to researchers, does that same closeness carry any moral weight? It is a question the scientific community is actively grappling with, and one worth sitting with as you continue your study of our primate relatives.

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8.5: Key Terms

Key Terms

Ancestral trait - A trait that has been inherited from a distant ancestor

Anthropoid (Haplorrini) – suborder of Primates that includes monkeys, apes, and humans

Arboreal – refers to living in trees

Bilophodont – molar pattern of cercopithecoid monkeys in which there are usually four cusps that are arranged in a square pattern and connected by two ridges

Brachiation - a form of locomotion in which the organism swings below branches using the forelimbs

Carnivorous – diet consisting primarily of meat

Convergent – refers to eyes that face forward in the skull

Derived trait – a trait that has been recently modified

Diurnal – active during the day

Folivorous – diet consisting primarily of leaves

Fovea – a depressed area in the retina at the back of the eye containing a concentration of cells that allow one to focus on objects very close to one's face

Frugivorous – diet consisting primarily of fruit

Grooming Claw – a claw present on the second pedal digit in prosimian (strepsirrhine) primates

Gummivorous – diet consisting primarily of gums and saps

Herbivores – diet consisting primarily of plants

Infraorder – taxonomic grouping of closely related families; a rank that sits immediately below a suborder and directly above a superfamily

Insectivorous – diet consisting primarily of insects

Ischial callosities – modified seat bones of the pelvis that are flattened and over which calluses form; function as seat pads for sitting and resting atop branches

Monomorphic – when males and females of a species do not exhibit significant sexual dimorphism

Morphological – physical structure of an organism

Nocturnal – active at night

Olfaction – sensory system related to smell

Phylogeny – the evolutionary history and genealogical relationship among groups of organisms, outlining how living things are related to each other through shared common ancestors

Post-orbital bar – a bony ring that surrounds the eye socket

Post-orbital plate/closure – a bony plate that provides protection to the side and back of the eye

Prehensile tail – a tail that is able to hold the full body weight of an organism, which often has a tactile pad on the underside of the tip for improved grip

Prosimian (Strepsirrhini) – suborder of Primates that exhibit more primitive or ancestral traits

Rhinarium – wet noses; resulting from naked skin of the nose which connects to the upper lip and smell-sensitive structures along the roof of the mouth

Scent marking – behavior of rubbing scent glands or urine onto objects as a way of communicating with others

Semi-brachiation – form of locomotion in which an organism swings below branches using a combination of forelimbs and prehensile tail

Sexual dimorphism – when a species exhibits sex differences in morphology, behavior, hormones and/or coloration

Suborder – secondary category of classification, typically found just below an order and just above an infraorder or family

Tapetum lucidim – reflecting layer at the back of the eye that magnifies light

Taxon – refers to a specific grouping at any rank in the taxonomic hierarchy (plural = taxa)

Terrestrial – refers to living or spending time on the ground

Tooth comb or dental comb – a trait of the front, lower teeth of prosimian (strepshirrine) primates in which, typically, the four incisors and canines are long and thin and protrude outward

Trichromatic color vision – being able to distinguish yellows and reds in addition to blues and greens

Y-5 Molar – molar cusp pattern in which five molar cusps are separated by a “Y” shaped groove

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9: PRIMATE BEHAVIOR

Learning Objectives

- Explain how primate social behaviors (touch, grooming, bonding) illuminate the biological basis of human social and physical needs.
- Evaluate competing claims about human uniqueness by comparing human traits to those observed in non-human primates and other animals.
- Critically assess the anthropocentric bias in scientific research and its influence on how "human uniqueness" has been defined over time.

9.1: So What Makes Us Human?

9.2: Did Dads Evolve?

9.3: The Anthropocentric Bias

9.4: Key Terms

9.5: References

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9.1: So What Makes Us Human?

> ***"The world is now dominated by an animal that doesn't think it's an animal. And the future is being imagined by an animal that doesn't want to be an animal."*** *(Challenger 2021:1).*

Picture this: Japanese macaques—Old World monkeys—riding like small jockeys on the backs of sika deer on Yakushima Island. The monkeys ride deer for transportation and sometimes appear to ride just for fun (Quaglia 2025). They've even been observed grooming the deer, but that's not the only human-like behavior they engage in.

Some macaques humorously make and throw snowballs. Others have been observed washing potatoes in the water; a trait the adults pass down to the babies who watch them. And yet, others appear to luxuriate in hot-spring baths. These macaques have even been recorded policing a strict social hierarchy where only select members have access to the springs, while the rest eek it out in the cold; a behavior highly reminiscent of the "have and have nots" social structure typical of many human groups.



Figure 9.1.1:Japanese macaques grooming and relaxing in natural hot springs. Image from Flickr/Ratcliff

In Japan, tourists flock to see these monkeys who seem to display remarkably human-like behaviors. But for anthropologists, these observations raise fascinating questions: Is riding deer and washing potatoes actually a sign of culture? How different is macaque behavior from human behavior, really? What do we share with other primates, and what makes us truly unique?

This reading tackles anthropology's most fundamental question: "What makes us human?" It's not an easy answer. We share nearly 99% of our DNA with chimpanzees—our closest primate cousins. That means the difference between humans and chimps comes down to a mere 1% of our genetic code. Yet we are undeniably different. After all, you're the one reading this textbook, not a chimpanzee. So what is this "little difference that makes the big difference," as the 2008 NOVA documentary *Ape Genius* puts it?

Tool Use

Humans are extremely adept at using tools. From the first hand axes created over a million years ago to today's smartphones and space stations, tools represent one of humanity's greatest achievements.



Figure 9.1.2: A juvenile capuchin monkey (*Sapajus libidinosus*) using a stone as tool to open a seed. By Tiago Falótico, CC BY-SA 4.0 via Wikimedia Commons

Before the 1960s, scientists considered tool use the "gold-standard" of human uniqueness. Tools, they believed, were made and used exclusively by humans. Then, a young researcher named Jane Goodall would shake the anthropological world. In 1960, while studying chimps in their natural habitat, she spotted a chimp squatting by a termite mound. Curious but careful not to disturb him, she watched from a distance as he poked long grass stems into the mound and then put them in his mouth. When he left, she tried it herself. To her delight, the grass emerged covered in termites. The chimp has been using it as a fishing rod for insects.

Later, Goodall would observe other chimps deliberately stripping leaves off twigs to create smoother, more effective tools. This wasn't just tool *use*; it was tool *modification*, which is essentially, toolmaking. When the famous anthropologist Louis Leakey received Jane's telegram describing her discovery, his response became legendary: "Now we must redefine tool, redefine man, or accept chimpanzees as humans."

Today, researchers have documented chimps making and using diverse tools both in the wild and in captivity: sharpened sticks used as spears to hunt bush babies, modified twigs for extracting termites, rocks for cracking nuts, bone picks to extract marrow bones, and even vines used as play toys. While chimps demonstrate the most diverse and complex tool use among among nonhuman primates, many other primate species use tools for highly specific purposes.

For instance, a wild female gorilla was observed using a branch to test water depth before wading into a swampy pool in the Congo, demonstrating innovation in meeting a specific ecological need (Breuer et. Al. 2005). Orangutans carefully select sturdy sticks to insert into bee hives in trees to obtain honey (van Schaik, C. P. et al. (2003). Clever capuchin monkeys in South America have been documented to engage in a multi-day, multi-step process of cracking palm nuts which requires planning, transportation of raw materials, and careful selection of nut-cracking sites that allow for easy escape from menacing jaguars. This type of **extractive foraging**, represents one of the highest cognitive demands among nonhuman primates.

Language

Language allows us to convey information and transmit knowledge across generations. But did you know that great apes can learn human sign language? The most famous example is Washoe, a female chimpanzee who learned American Sign Language, as did a gorilla, named Koko. By age five, Washoe could sign over 350 words, form simple sentences, and use basic grammar. While some researchers dismissed this as merely responding to human prompts, others noted something unexpected: Washoe would sometimes sign unprompted and create new combinations to describe unfamiliar things. When she saw a swan for the first time, she signed "water" and "bird" together---inventing her own description.

Many other chimps have been language trained since Washoe, representing a trait that all great apes appear capable of learning to some degree. So, while humans clearly use language in more nuanced and sophisticated ways, the capacity for language alone cannot explain why humans are so unique among primates.

Theory of Mind

With language and toolmaking off the table as uniquely human traits, researchers turned to something more abstract: self-awareness. The test for self-awareness is surprisingly simple---responding to and recognizing your reflection in a mirror. Many species, like cats and dogs, pass a mirror without looking, or think that the reflection is another animal. Human babies develop this ability around 18-24 months of age. But humans aren't alone.

The gold standard experiment for self-awareness is what researchers call the "**rouge test**." The test involves putting a bit of lipstick or blush on an animal's face, then putting them in front of a mirror to observe their reaction. Before ~18 months of age, human babies smile and play with the "other baby" in the mirror, completely unaware of the makeup. Around 18-24 months, something clicks and they begin to notice the makeup, and may even become distressed, trying to rub it off rather than playing with their reflection

Why does this matter? Recognizing yourself in a mirror demonstrates the ability to think about oneself as an independent being with thoughts separate and distinct from—what psychologists call **theory of mind**. Theory of mind means understanding that other people have thoughts and feelings different from yours. It enables children to grasp other people's intentions and emotions and underlies important social behaviors like sharing, helping, friendship, and even deception.

Few animals pass the rouge test. Besides humans, the list includes great apes, some monkeys, dolphins, orcas, and elephants (all some of the most intelligent mammals on the planet). Elephants are particularly fascinating because wild elephants have been observed touching, rolling, and picking up the bones of deceased matriarchs, suggesting they're capable of grief, empathy, and understanding death itself.

Culture

For decades, scientists believed that culture was unique to humans since, from our human point of view, only we have passed down knowledge and customs from one generation to the next. But evidence has continued to mount that other species engage in behavior that looks like culture. Remember those Japanese macaques sitting in the hot springs? Young monkeys learn the social hierarchy and thermal hot spring etiquette—including which monkeys get preferential access—from observing their elders and carry those behaviors into adulthood. Among chimpanzees, groups in different regions display culturally specific behaviors. You could easily identify a chimpanzee from Fongoli because only Fongoli chimps enjoy dunking themselves in ponds (other chimps hate water) and making spears to kill bush babies.

Primatologist Robert Sapolsky has recorded a fascinating example of not just culture, but cultural *change*, among the Forest Troop baboons in Kenya. Normally, baboon culture is rather violent; males constantly fight over access to females, food, resting spots, or seemingly nothing at all. Lower ranking baboons get bullied relentlessly by higher-ranking individuals seeking ego boosts (sound familiar?). In 1986, an outbreak of tuberculosis killed off the most aggressive males. Sapolsky abandoned his study for ten years, but when he returned, a dramatic and unexpected change had taken place: troop members sat closer together, groomed each other more frequently, and higher-ranking baboons stopped violently venting on subordinates. Life improved for lower-ranking baboons who no longer showed markers of chronic stress.

The most remarkable observation, however, was that the troop had maintained this peaceful culture despite a complete turnover in the male population. Typically, aggressive adolescent males leave their birth troop and fight their way into new ones. Yet the Forest Troop somehow assimilated these surly newcomers without losing its peaceful culture. Sapolsky suspects that female baboons' friendliness towards newcomers plays a key role—as if the females "saw the light" and realized life is better with peaceful males.

Despite such evidence, the culture hypothesis remained hotly debated for years. But scientific consensus is shifting as more examples emerge. Researchers have discovered culture in many other animals: Australian humpback whales whose songs go through phases of popularity and decline, just like human pop music, and bottlenose dolphins of the Florida Keys who hunt communally by swimming in tight circles on the seabed and creating mud rings that confuse and trap fish (something that only this particular group of dolphins does). Even crows and ravens make and use tools, passing these designs and mental templates to other, unrelated crows. The short video below goes into greater depth about some of these examples.

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

The Atlantic. (2018, January 12). *What Explains Bizarre Animal Behavior?* [Video] YouTube https://www.youtube.com/watch?v=TAKIsFshLyI

Pro-social behavior

Since the early 2000s, scientific consensus on uniquely human traits has focused on what researchers call **pro-social behavior**. This includes friendliness, altruism, an active hands-on teaching (as opposed to the trial-and-error-style learning that chimpanzees engage in), the desire to encourage others, and the ability to share goals. The 2008 NOVA documentary, *Ape Genius*, explores these pro-social behaviors through a series of creative experiments involving chimpanzees and human children. Consider something as simple as pointing. We take it for granted, but it's a complex skill non-human primates lack. Pointing directs someone's attention toward a third object. You expect the other person to understand where you attention is focused and that you want to look at the same thing so you can share knowledge or work toward a common goal. This creates a communicative triangle between you, the other person, and the object which is critical for communication, teaching, and teamwork. As anthropologist Rebecca Saxe explains in *Ape Genius*, "It's a special cognitive achievement...kids do this naturally, almost immediately...[but] curiously, apes can't get into that" (NOVA 2008).

Altruism

Altruism is a behavior that benefits another individual while involving some risk or sacrifice to the performer and represents another form of pro-social behavior. The most fundamental altruistic act, protecting offspring, appears universally among mammals and birds. Among primates, though, altruism often extends beyond close genetic relatives. Researchers have documented female baboons chasing hyenas to protect unrelated young males, female langur monkeys defending unrelated infants from infanticidal males, and chimpanzees adopting orphans (though these infants are typically relatives).

Primate Profile | Bonobos

Bonobos are famously known as the friendliest of the great apes. Not only do these close primate relatives demonstrate extreme altruism, they also exhibit empathy and concern for others, including bonobos they've never met. Here are some documented examples of pro-social behaviors in wild and captive bonobos:

Food Sharing with Non-Kin

Bonobos show unusual tolerance around food and frequently share voluntarily, even with unrelated individuals. In experiments, bonobos willingly opened a door allowing another bonobo (including strangers) to access food (Hare & Kwetuenda 2010). They've also been observed offering and sharing feeding sites. Interestingly, this sharing occurs outside mating contexts, suggesting genuine prosocial motivation.

Helping Strangers

Bonobos help unfamiliar individuals without expecting immediate rewards**,** which is rare among nonhuman primates. Examples include helping another bonobo get an out-of-reach object and allowing a stranger into a feeding room even when it reduced their own food intake. This behavior, which can be considered a form of "xenophilia" (attraction to strangers) is not seen in common chimps.

Triadic Reconciliation

Bonobos sometimes intervene in conflicts between others and facilitate peace, reducing tension for the entire group---a group-level benefit.

Consolation Behavior

Bonobos frequently show empathic consolation after aggression or distress by embracing, grooming, or gently stroking distressed individuals. Consolation occurs between non-kin and even young bonobos console adults, which is rare in other primates.

Adoption of Orphaned Bonobos

Field reports have documented how bonobo orphans have been adopted by unrelated females and even by adult males, with no reproductive benefit, providing long-term care with substantial energetic cost.

Overall, bonobos display highly flexible, emotionally driven altruism. They're more tolerant, cooperative, and xenophilic than chimpanzees. Their altruism helps illustrate the evolution of human prosociality, especially empathy and cooperation.

Source: Adapted from "So, What Makes Us Human?" by Jacqueline McGinty in Palmiotto A, Homsey-Messer L, Ford B, Poole A, Adams A, Allard F, Chadwick W. 2022. *Introduction to Anthropology: Holistic and Applied Research on Being Human*. Indiana University of Pennsylvania. Open Educational Resource (OER) available at https://www.iup.edu/anthropology/research/oer.html.
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9.2: Did Dads Evolve?

Most male mammals are not involved in raising their offspring. Anthropological observations of fatherhood can provide insight into how—and why—humans are so different.

by Elizabeth Preston

1 SEP 2021

Did Dads Evolve?

Lee Gettler is hard to get on the phone, for the very ordinary reason that he's busy caring for his two young children. Among mammals, though, that makes him extraordinary.

"Human fathers engage in really costly forms of care," says Gettler, an anthropologist at the University of Notre Dame. In that way, humans stand out from almost all other mammals. Fathers, and parents in general, are Gettler's field of study. He and others have found that the role of dads varies widely between cultures—and that some other animal dads may give helpful glimpses of our evolutionary past.

Many mysteries remain, though, about how human fathers evolved their peculiar, highly invested role, including the hormonal changes that accompany fatherhood. A deeper understanding of where dads came from, and why fatherhood matters for both fathers and children, could benefit families of all kinds.



Figure 9.2.1: Father and daughter. Photo by kabita Darlami on Unsplash

"If you look at other mammalian species, fathers tend to do nothing but provide sperm," says Rebecca Sear, an evolutionary demographer and anthropologist at the London School of Hygiene and Tropical Medicine. Moms carry the burden in most other animals that care for their kids too. (Fish are an exception—most don't tend their young at all, but the caring parents are usually dads. And bird couples are famous for co-parenting.)

Even among the other apes, our closest relatives, most dads don't do much. That means moms are stuck with all the work and need to space out their babies to make sure they can care for them. Wild chimps give birth every four to six years, for example; orangutans wait as long as six to eight years between young.

The ancestors of humans, though, committed to a different strategy. Mothers got help from their community and their kin, including fathers. This freed them up enough to have more babies, closer together—about every three years, on average, in today's

nonindustrial societies. That strategy “is part of the evolutionary success story of humans,” Gettler says.

Doting Gorilla Dads

Some clues about the origin of doting fatherhood come from our close primate relatives. Stacy Rosenbaum, a biological anthropologist at the University of Michigan, studies wild mountain gorillas in Rwanda. These gorillas provide intriguing hints about the origins of ape dads, as Gettler and co-authors Rosenbaum and Adam Boyette argue in the 2020 *Annual Review of Anthropology*.

Mountain gorillas are a type of eastern gorilla. They differ from western gorillas—a separate species, more often seen in zoos—in their habitat and diet. Rosenbaum is more interested in another thing that sets mountain gorillas apart: “Kids spend a ton of time around males,” she says.

Those males may or may not be their dads. Male mountain gorillas don’t seem to know or care which young are theirs. But nearly all males tolerate the company of kids. Unlike any other great ape that’s been studied in the wild, these males—bruisers twice the size of females, with huge muscles and teeth—are essentially babysitters. Some pick up the kids, play with them, and even sleep cuddled together.

This male company can protect very young gorillas against predators, and it keeps the young from being killed by intruding males. Another important benefit might be social, Rosenbaum speculates. The young gorillas mingling around an adult male might pick up social skills like human toddlers do from their peers at day care. Additionally, research has shown that the relationships between young gorillas and adult males persist as those kids grow up.

Another tantalizing hint about how male gorillas benefit the young in their group comes from a recent paper on young mountain gorillas whose mothers died. Losing their mothers didn’t make these orphans more likely to die themselves, the researchers found. Nor did they experience other costs, such as a longer wait before having their own young. The orphans’ relationships with others in their group, especially dominant males, seemed to protect them from ill effects.

Mountain gorilla males aren’t the only primates to ally with kids. Adult male macaques also spend time with young. And baboon males form “friendships” with females and their young, which are often (but not always) their own offspring. These behaviors cost the male primates almost nothing. So, while the males may give their own kids a survival boost, it’s not a big deal if they spend time with some unrelated kids too.

Are Dads Sexy?

But babysitting may benefit male gorillas in another way too: by making them more attractive. “One of our speculations is that females actually prefer mating with males who do a lot of interacting with kids,” Rosenbaum says. She’s found that male gorillas who do more babysitting earlier in life go on to father many more children when they’re older. Macaques, too, seem to be more attractive to females if they’ve spent more time hanging out with kids.

Anthropologists used to assume that fatherly behavior could evolve only in monogamous animals, Rosenbaum says. Species like the mountain gorillas undermine that assumption. They also show that, despite what scientists have long thought, male animals don’t have to choose between spending their energy on mating or parenting. It seems taking care of kids can be a way of getting mates.

> ***Taking care of kids can be a way of getting mates.***

Studies of human dads and stepdads have hinted at the same idea. “A lot of guys will willingly enter into relationships with kids they know aren’t theirs,” says Kermyt Anderson, a biological anthropologist at the University of Oklahoma. That investment might seem paradoxical from an evolutionary perspective. But Anderson’s research suggests that men invest in stepkids and even biological kids partly as an investment in their relationship with the mother. When that relationship ends, fathers tend to become less involved.

A human dad who cares for his children or stepchildren is different, of course, from an ape or monkey who just lets kids hang around. But Gettler and Rosenbaum wonder whether our own ancestors had similar habits to a mountain gorilla or macaque.

Under the evolutionary pressures they faced, these friendly tendencies toward kids could have ratcheted up into devoted fatherhood.

Many Kinds of Fatherhood

It's clear human fathers are unusual in their attention to their children. "However, it's also clear that fatherhood in humans is quite variable," Sear says. Not all dads are doting, or even present.

But that doesn't necessarily affect basic survival. In a 2008 paper, Sear and co-author Ruth Mace asked whether children with absent fathers are likelier to die. They reviewed data on child survival from 43 studies of populations around the world, mostly those without access to modern medical care. They found that in a third of the studies looking at fathers, kids were more likely to survive childhood when their dad was around. But in the other two-thirds, fatherless kids did just as well. (By contrast, every study of children without mothers found they were less likely to survive.)

"That is not what you would expect to see if fathers are really vital for children to thrive," Sear says. Rather, she suspects that what's vital are the jobs fathers perform. When a father is missing, others in the family or community can fill in. "It may be that the fathering role is important, but it's substitutable by other social group members," she says.

What is that role? Historically, Gettler says, anthropologists have viewed fatherhood as all about "provisioning"—bringing home the bacon, literally. In some foraging communities, more successful hunters also father more kids. But Gettler hopes to help expand the definition of a dad. Research has shown that fathers can have important roles in directly caring for their children, for example, and teaching children language and social skills. Fathers may also help their children by cultivating relationships in their communities, Gettler says. When it comes to survival, "networking can be everything."

A dad's job also varies culturally. For example, in the Republic of the Congo, Gettler works with two neighboring communities. The Bondongo are fishers and farmers; they value fathers who take risks to gain food for their own families. Their neighbors, the BaYaka, are foragers who value fathers who share their resources outside their families.

"In the West, we have this idealization of the nuclear family," says Sear: a self-reliant, heterosexual couple in which Dad does all the provisioning and Mom all the child care. But worldwide, she says, families like this are very rare. A child's biological parents may not live together exclusively, for life or at all, Sear writes in a recent paper. Child care and food can come from either parent—or neither. Among the Himba of Namibia, for instance, children are often fostered by extended family.

"Possibly the key defining feature of our species is our behavioral flexibility," Sear says. Assuming that certain roles are "natural" for fathers or mothers can make parents feel isolated and stressed, Sear writes. She hopes research can broaden our understanding of what fathers are for, and what a human family is. That might help societies to better support families of all kinds—whether they have dads like Gettler who are busy chasing the children around, or dads who are away fishing, or no dads at all.

"I think we need to take a much more nonjudgmental view of the human family and the kinds of family structures in which children can thrive," Sear says, "to improve the health of mothers, fathers, and children."

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9.3: The Anthropocentric Bias

Humans Studying Humans

Here's an uncomfortable truth: anthropologists are humans studying what makes humans unique. No matter how hard scientists strive for objectivity, our own biases inevitably shape our studies and interpretations.

We're studying ourselves, which makes true objectivity nearly impossible. We naturally treat humans as beings with agency and self-awareness that other animals supposedly lack. As a result, our criteria for what makes humans unique keeps evolving and becoming more specific as we discover just how diverse and capable primate communities really are.

Think about it: We've found primates that use tools and complex communication systems, possess self-awareness, and demonstrate compassion, empathy, and altruism. We've even discovered that other species like chimps, have dark, aggressive sides and engage in the same violent, even genocidal behaviors that humans do. Anthropology's goalpost constantly shifts as we try to explain why humans are more than "just another primate."

Maybe the question itself is flawed. Perhaps it's not about identifying a single trait that makes us unique, but rather exploring the *extent* to which humans differ in these traits. Obviously, the incentive to modify a twig to snack on ants differs vastly from the motivation to develop smartphones, stockpile nuclear weapons, and land robots on Mars. Perhaps this, then, is the "little difference that makes all the difference."

But let's not forget, as Lulu Miller points out in her excellent book, *Why Fish Don't Exist* (2020), other animals

> "can outperform humans on nearly every measure supposedly associated with our superiority. There are crows that have better memories than us, chimps with better pattern-recognition skills, ants that rescue their wounded, and blood flukes [a parasitic worm] with higher rates of monogamy. When you actually examine the range of life on Earth, it takes a lot of acrobatics to sort it into a single hierarchy with humans at the top. We don't have the biggest brain or the best memory. We're not the fastest or the strongest or the most prolific. We're not the only ones that mate for life, that show altruism, use tools, language. We don't have the most copies of genes in circulation. We aren't even the newest creation on the block." (Miller 2020:146).

Bringing Down the Ladder of Sapien Supremacy

Primatologists, anthropologists, biologists, indigenous cultures worldwide, and even kindergartners recognize a fundamental truth: we humans are kin with all living things. Throughout this unit, we've focused primarily on our similarities with our primate relatives. Our long evolutionary legacy reveals so many key aspects of our human behaviors and feelings—everything from our intense need for belonging to our need for physical touch and closeness, right down to our very nervous system with its highly developed social engagement pathways.

Yet, we still struggle to accept that we are animals. The depth of this denial connects directly to many planetary crises we face today. The cultural narrative dominating our modern era positions humans as separate from or superior to nature. But time and again, nature delivers stark reminders that just like every other animal on this planet, we too must face unpredictable selective pressures, whether that's a viral pandemic, a lightning-sparked wildfire, or devastating floods.

Reconnecting with Our Place in Nature

At a time when many of us experience a crisis of belonging, we should find reassurance in our connection to the living world. We can cultivate closer relationships with our non-human kin by learning to identify the trees, birds, insects, and plants that inhabit our bio-region. Consider this striking fact: most humans can identify and distinguish between more brand logos, whether it's the slanted H in an oval versus an H in a square, or various swooshes and stripes on shoes, than they can identify species of bird, trees, insects, or plants. Even eating, an act that connects us directly to the natural world daily, seems disconnected from the oceans and lands, near and far, from which our food originates.

Yet the more fluent we become in the language of our landscape—the *natural* landscape—the more anchored we feel in the living

world around us. We develop a deep knowing that we're never alone and that we always belong to the community that is LIFE. As Carol Kaesuk Yoon says, "To recognize the life around you is to recognize where you are, who you are, and what the world around you really is" (2009:163).

This explains why certain experiences move us so profoundly: walking on the beach while gazing at the ocean's vastness, standing among towering redwoods, sitting by a rushing river that's constantly flowing yet always there, or looking up at the night sky to find Orion's belt or a bright planet. These moments inspire awe and remind us that we're connected to something far bigger than ourselves and the human-constructed world.



Figure 9.3.1: Admiring the mountain view. Image by ivabalk from Pixabay

The Human Animal

As writer Melanie Challenger puts it,

> "All that we do, we do as animals. But we justify it as humans. The way we've structured the world is little more than the intuition of an animal whose greatest interests lie with its own kind...While the slightest insight into our experiences shows how necessary it is to care about human lives, this doesn't separate us from the rest of our planet's life. Human life remains an animal life. Our awareness and our exchanges of ideas make us a powerful and sensitive animal, but none of this brings our animal life to an end. That this idea has had such extraordinary influence across our societies is only now becoming clear. It is surfacing because it matters more than it ever has that ten thousand years of modernity have delivered an animal that doesn't think it's an animal." (2020:52-53).

The challenge before us isn't to deny our humanity or diminish human achievement. Rather, it's to recognize that our humanity exists *within* our animal nature, not separate from it. Understanding this connection doesn't make us less extraordinary. It situates our distinctive qualities within the broader tapestry of life on Earth.

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9.4: Key Terms

Extractive foraging - the process of obtaining food that is embedded or protected by a hard or tough outer layer, such as underground roots, nuts, eggs, or wood-boring insects. This type of foraging requires intensive manipulation, often involving tool use, to access the food.

Rouge test – psychological experiment that assesses self-awareness by placing a mark on a subject's face. If the subject recognizes that the mark is on their own reflection in a mirror and tries to touch the mark on their own face, it indicates they have passed the test, showing self-recognition.

Theory of mind - the ability to understand that other people have their own mental states, such as beliefs, desires, and intentions, which may differ from one's own.

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10: STUDYING THE HUMAN PAST

Learning Objectives

- Apply the principles of comparative anatomy to understand evolutionary relationships between humans and other primates.
- Evaluate the challenges in studying the human fossil record.
- Identify the key anatomical adaptations that enable bipedal locomotion.
- Explain how the study of bipedalism demonstrates the on-going nature of scientific discovery and theory revision.

10.1: Finding and Studying Hominin Remains

10.2: The Fossil Record is Tricky to Interpret

10.3: How Apes Reveal Human History

10.4: The Evolution of Upright Walking

10.5: Key Terms

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10.1: Finding and Studying Hominin Remains

The Grand Canyon of Human Evolution – Africa's Great Rift Valley



Figure 10.1.1: A view of the Great Rift Valley in Kenya. (Image from Wikimedia Commons)

A look at the location of early hominin remains in Africa dating between 7 and 2 mya—the latter being believed as the approximate time that hominins left Africa for the first time—reveals an interesting distribution pattern. Aside from a single location in the present-day country of Chad (north Africa), the remaining hominin remains are concentrated in two regions: east Africa's **Great Rift Valley** region and southern Africa. This pattern leads us to ask whether early hominins lived in other parts of Africa. The answer is that, while certain regions may have been favored for various environmental or other reasons, the distinctive spatial pattern is likely the result (a least in part) of other factors. In other words, it is 'difficult to become a fossil', and once **fossilized**, to be 'discovered'; a set of limitations which help account for the large number of remains found in the Great Rift Valley and southern Africa, and the fact that relatively few early hominin remains have been found so far.

Understanding fossilization

Dead organisms (including hominins) typically do not become fossilized, a process which first requires that the organism be protected from microbial decay, insects and scavenging animals. Such initial protection is more likely when the body is quickly buried by sediments associated with a body of water (e.g. flooding; falling into the water) or by slope runoff. Once buried, the soil conditions also need to be conducive to the preservation of the body by slowing or stopping bacterial and chemical decomposition. Such favorable conditions include low temperatures, dry conditions (e.g. deserts), anaerobic (low / no oxygen levels) conditions (e.g. wetlands), and low soil acidity. Over time, the (often partial) physical remains of the protected and preserved organism become 'fossilized', a process which can take tens of thousands of years and which involves the gradual replacement of the minerals calcium and phosphorus in bones and teeth by the rock-forming minerals iron and silica present in ground water. Often dating to hundreds of thousands or millions of years ago, hominin fossils therefore appear as durable 'stone-like' copies of past individuals. Of course, the accumulation of sediments above the fossilized remains over such long periods of time results in hominin fossils being locked inside geological strata that are often located deep under the present-day surface. Finding such fossils then becomes the next challenge for **paleoanthropologists.**

Large numbers of hominin fossils have been found in in the Great Rift Valley, a wide and long geological rift region in East Africa that consists of a series of deep trenches. The area's past and present environment appears to have provided ideal conditions for the fossilization and discovery of hominin fossils. To begin, the region has long been geological active, as evident from its many and frequent volcanoes, geysers and earthquakes. Together, these features have increased the likelihood of hominins being buried under sediments, which in some cases included volcanic tuff (formed from ejected volcanic ash). The other significant factor is that many parts of the Great Rift Valley are presently dry, although prone to heavy downpours during the rainy season.

Importantly, these rains result in the erosion of exposed stratified sediments at the edges of the depressions, which in turn occasionally exposes buried hominin fossils. Thus, paleoanthropologists do not – unlike other archaeologists – typically excavate 'downward' from the surface to reach fossils. Instead, they wait for them to emerge from a slope's sedimentary strata. Not surprisingly considering the process by which hominin remains are found, these remains are often highly fragmented. The process of locating, isolating and excavating hominin fossils is often painstaking and can take years and require significant amounts of financial resources.

The South African fossil context

As mentioned earlier, the southern part of Africa has also yielded several important hominin fossils, although the setting within which such discoveries have been made is very different from that encountered by paleoanthropologists working in the Great Rift Valley region. Most important, many of southern Africa's hominin fossils have been found in limestone caves, with the remains encased in a calcium carbonate matrix. In this case, preservation was possible because the hominin individuals ended up in the limestone caves or depressions, either because they died there or, according to some paleoanthropologists, because they were dropped into such spaces from trees by leopards who had previously preyed on them. The later discovery of the fossils would then have to wait until the cave mouth was found or when new openings into ancient karst (limestone) formations appeared as a result of erosion – limestone is relatively soluble in rainwater. What about the rest of Africa? Why haven't hominin fossils been found outside southern Africa's karst regions and the Great Rift Valley? As mentioned earlier, different factors may have played a role. Thus, hominins who lived in Africa's more humid and forested areas were likely quickly exposed to humidity, insects, animals, and ultimately decay. This helps explain why fossils are rarely found in tropical forests. On the other hand, factors having more to do with the visibility and exposure of fossilized remains would have played a role in other regions of Africa.

Dating Techniques

The dating of hominin remains is an essential task in the reconstruction of the hominin phylogeny. Even as the various dating methods employed by paleoanthropologists present several challenges in regard to both **accuracy** (i.e. how close a measurement is to the true value) and **precision** (i.e. how close measurements of the same item are to one another), scientific advances over the past decades have played a central role in helping scientists sort out the chronology of different hominin individuals and the species they belong to. As suggested by the label, **'relative' dating methods** focus on determining the relative age (i.e. older vs younger) of remains, which is carried out through a range of methods, including (among others): their position in a stratigraphic sequence; fluorine dating (based on the accumulation over time of fluorine in animal and human bones); and the use of index fossils (which are known to belong to specific time ranges and found at multiple locations). Of course, reconstructing the hominin phylogeny is ultimately dependent on 'absolute' dates, which are (more or less) accurate age determinations in years.

Absolute dating methods include a range of techniques, of which **radiometric methods** are the most widely used (see research methods module). Such techniques are based on the known radioactive decay rate of different elemental isotopes, such as **Carbon 14** (which decays to Nitrogen 14: half-life of 5730 years) and **Potassium 40** (which decays to Argon 40: half-life of 1.25 billion years). Importantly, these two radiometric dating methods differ in their specific practical uses. Thus, radiocarbon dating is used to date once-living organisms and plants (whose levels of Carbon 14 begin to decrease after death), although the method only extends back to about 50,000 years ago, by which time there is too little Carbon 14 left to measure. In contrast, due to the very long half-life of Potassium 40, the Potassium-Argon method is most useful in (volcanic) sediments that are older than about 100,000 years old. Moreover, the technique, which dates the age of sediments rather than the fossilized skeletons themselves, has proven especially useful in dating volcanic strata, such as those lying below and above hominin remains in the Great Rift Valley (which saw elevated levels of volcanic activity in the past).

Scientific techniques have also proven essential in the reconstruction of past environmental conditions and hominin diet. The most direct approach employed by paleontologists consists of identifying the fossilized animal and plant remains associated with hominins. A parallel technique involves the determination of Carbon 13 and 12 ratios present in the animal bones and the soils. Importantly, C3 plants (trees, nuts, bushes and cool-season grasses in wet, wooded environments) use a different carbon pathway than C4 plants (grasses and sedges in open grasslands / tropical savannas). This results in different Carbon 13 to 12 ratios between the two carbon pathways and allows paleoanthropologists to reconstruct the environment in which early hominins lived. One interesting illustration of how the method has been used to adjust some of our views concerns the commonly held notion that early hominins first evolved in a savanna setting associated with the development of bipedalism.

Recent paleoenvironmental research has in fact shown that the earliest hominins lived in heavily forested environments. In regard to diet, interpretations have traditionally been based on tooth and jaw morphology. For example, the large jaws and molars of several early hominin species has led to the view that much of their diet consisted of (hard) nuts and seeds. However, recent

studies of Carbon 13 and 12 isotopes in tooth enamel has shown that at least in the case of one later hominin species with a very large jaw and molars, C4 plants (i.e. tropical grasses) played a large role in the diet, rather than the C3 plants (i.e. nuts and seeds) initially believed to be the focus of its diet. Whether this reassessment of diet also applies to earlier hominins remains to be seen.

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10.2: The Fossil Record is Tricky to Interpret

The Fossil Record is Tricky to Interpret

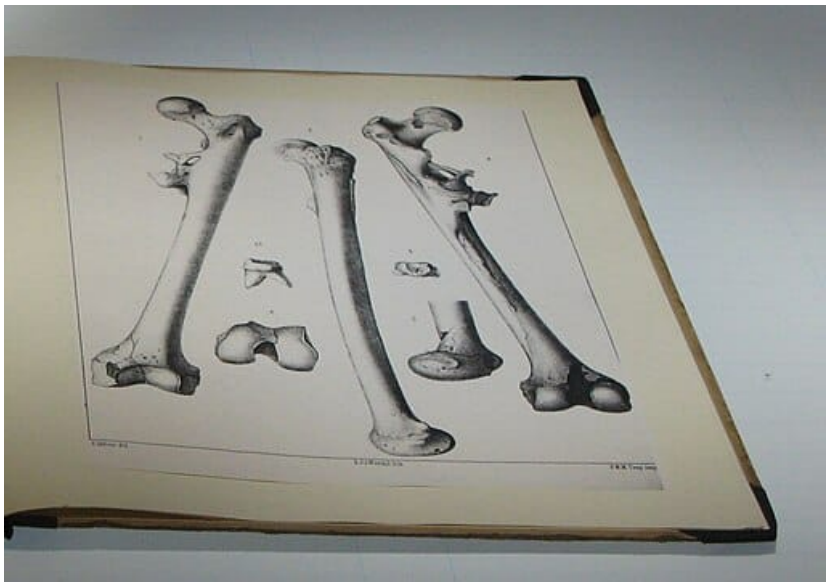


Figure 10.2.1: Drawings by Dutch anthropologist Eugène Dubois of a molar and a femur of *Pithecanthropus erectus* (now *Homo erectus*) (1894). (Naturalis Biodiversity Center, Public domain, via Wikimedia Commons)

Since the turn of the century, researchers have been discovering fossils and identifying new species when they have unusual appearances or seemingly new traits. However, as more information is uncovered from the fossil record and through molecular biology, our understanding of early species has developed. As a result, species are continually split apart or lumped together. For example, formerly *Homo erectus* and *Homo ergaster* were seen as different species, but today, many researchers believe they represent variation within a single species, which is now collectively called *Homo erectus*.

Identification efforts are hampered by several factors. First, there are relatively few fossilized remains available for study. Rarely do researchers find a complete fossilized skeleton of an individual. Instead, it is more common to find broken, fragmented pieces of bone that only make up a portion of a skeleton. Some parts of the skeleton may be completely absent at an excavation site. Some pieces may be so broken that it is difficult to analyze. Therefore, it is often featured in the news if an intact skull or a mostly complete fossil skeleton is discovered.

Most species are represented by incomplete specimens. In fact, some species may only be known by a handful of bones, and different bones may be known for different species. For example, some species are known primarily from cranial remains, while other species are only known through post-cranial remains, such as *Orrrorin tugenensis*. How can we confirm they are different species based solely on bone characteristics in the absence of molecular biology or dating techniques?

Second, there is a lot of variation within a population. When researchers analyze fossils, there is the challenge of determining whether two fossils look different because of normal variation or because they are different species. For example, look around your classroom or the grocery store. People look different, but we are all part of the human race. There are differences in our features that can be accounted for by our ancestry, family lines, and geographic differences. All of these elements result in a range of physiological and cultural distinctions. For example, the Tarahumara (Rarámuri) are renown runners while the *ama* of Japan are renown divers. This type of individual variation is evident in nearly all species that exist today and even those that are long extinct. The same can be said for any existing species as not all German Shepherd dogs look the same nor do all orange tabby cats.

It is likely that different species in the past had a lot of variation within their populations. This variation could be because of age (comparing young and full-grown examples) or sex (comparing male and female examples in groups with significant **sexual dimorphism**). Additionally, human groups living in some regions today display considerable skeletal differences from populations of *Homo sapiens* that lived in the same area thousands of years earlier. Populations change over time, and people move about the landscape. Researchers have even documented changes in the modern humans' average stature over time. Therefore, it's difficult

to define clear boundaries for humans, let alone any of our ancestors.

Third, even scientists are occasionally stymied by bias. Many of us have preconceived notions regarding how skeletal adaptations should appear in the fossil record. For example, think about how Neanderthals are traditionally portrayed in popular media. Until recently, Neanderthals in television shows, movies, and commercials were depicted as incompetent relatives of modern humans. Consider, too, the misconceptions surrounding natural selection and evolution as being progressive and leading to more "advanced" features, which became a standard framework within modern science. Sometimes, people must consciously remind themselves that evolution is ***not*** a unilineal, progressive matter, and that our ideas about how evolution works have evolved themselves in light of new evidence from genetics and the fossil record.

This notion of evolutionary progress had a strong influence on early taxonomic classifications of species which often focused on the development of modern humans from primitive origins. People believed that one could easily trace evolved characteristics through the fossil record. However, people now recognize that most species have a suite of more “primitive” and “evolved” (“**ancestral**” and “**derived**”) characteristics, even modern humans.

As discussed in the previous lessons, species are not evolving in a predictable, unilinear fashion. So, it is possible that many hominin species within the *Homo* genus may have “evolved” and “primitive” characteristics. Each species and even individuals within a species have a mix of traits that include old adaptations (***mosaic evolution***) persisting through time and new changes that distinguish species. Therefore, identifying fossil species is not always clear cut.

Additionally, a number of new species (e.g., Luzon Man, Dragon Man) have been discovered in recent years that cause us to reconsider how we understand human evolution. These discoveries increasingly emphasize the problem of distinguishing separate species from the perspective of reproductive isolation and biological species. In fact, just as we now know that Neanderthals interbred with modern humans and Denisovans, the same may be said of other recent discoveries because these early human species were never truly, reproductively isolated from one another, meaning gene drift and gene flow played important roles in the distribution of traits seen within and across hominin species. It is likely that future research will focus more on **hybridization** of early human species rather than trying to finalize a phylogeny or distinguish distinct species.

Finally, taphonomic processes impact the shape and condition of fossilized remains. **Taphonomy** is the study of biological and geological processes that impact remains after death. Time and natural processes can warp or disfigure fossilized remains. After all, fossils are not bones; they are created when bones or other organic remains are covered in sediments and, over thousands of years, the minerals in the soil leech into the bones and replace organic material.

Furthermore, **fossilization** is a rare process, and few species are identified by complete skeletons. This begs researchers to consider how many species are not represented at all in the fossil record. How many species may have existed that left no evidence for archaeologists to find? The fossil record is like a thousand-page book that has been shredded into a million pieces and scattered to the wind. Paleoanthropologists find a few of those shredded pieces and try to decipher how long the book is and what the story is about. It is difficult to know if you have a representative sample of the entire book or know what parts might be missing. The task is understandably difficult but not impossible.

Based on these considerations, some researchers argue that new species are assigned somewhat carelessly and do not adequately consider skeletal completeness, bone traits, and natural changes. Therefore, the organization of the human family tree is necessarily fluid, and species are grouped and ungrouped continually over the years. The classification of species has grown organically instead of being scrutinized in a systematic matter. Some researchers argue that paleoanthropologists should inventory and re-analyze all known fossils and critically review their characteristics to redefine the family tree of early humans.

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10.3: How Apes Reveal Human History

Great apes provide a window into the story of human evolution—and that's one more reason to protect them.

by Mary Shirley Mitchell

24 JUN 2021 | Originally Published on the SAPIENS.org website



Figure 10.3.1: Except for humans, every great ape is endangered—many at great risk of going extinct. There are fewer than 300,000 chimpanzees living in the wild. (USAID Africa Bureau, Public domain, via Wikimedia Commons)

Primate Kinship

When I was a kid, every trip to the zoo featured a visit to the orangutan habitat. I was fascinated by the animals' long fingers, how they took shelter when it started to rain, the affection they showed for their children, and the way they stretched after sitting too long in one position. Sometimes watching them felt like watching any other animal at the zoo, but sometimes it felt like watching people who happen to be visiting a nearby park. I swear I knew what they were thinking and feeling.

As an adult anthropologist, the sense of kinship I felt as a child has been brought into focus. Apes are our closest surviving relatives.

There was a time not so long ago when planet Earth was filled with a variety of our close relations, from *Homo erectus*, which looked quite a lot like modern humans, to *Paranthropus boisei*, which looked much less so. Each one carried a legacy: vital genetic, behavioral, biological, and geographic information about our shared origins. They were all strands in the interconnected web of humanity.

Today *Homo sapiens* are the only members of the *Homo* genus left, but we don't stand entirely alone. If we zoom out a little to look at our family *Hominidae*, four genera of great apes remain: us, chimpanzees, gorillas, and orangutans.

Looking at the numbers, there are approximately 7.67 billion people on the Earth today. In contrast, according to the World Wildlife Fund, the wild chimpanzee population is under 300,000, wild orangutans are fewer than 120,000, and although gorillas are notoriously hard to count, it is estimated there are some 100,000–200,000. Every great ape is endangered—except us.

The tragedy of those numbers is apparent to anyone who cares about conservation. We lose species to extinction every day,

driven by economically motivated habitat destruction or unfettered consumerism. Wherever humans go, biodiversity often suffers, and we are everywhere.



Figure 10.3.2: Habitat destruction from palm oil production (shown here in Sumatra) and other industries threatens primates. (Hayden, CC BY 2.0 <https://creativecommons.org/licenses/by/2.0>, via Wikimedia Commons

Great apes are special because they are the closest remaining threads on that web of humanity, and we can never recover the information they have to share about our origins once they are lost. Apes are uniquely impactful to the field of anthropology, where we researchers look to the past to understand our present. If the desire to preserve biodiversity isn't enough to save the apes, then unlocking the human story should be a further impetus for their conservation.

Consider Bipedalism

One of the most fundamental things about being human is that we walk upright on two legs. Some anthropologists have even suggested that this feature allowed us to become successful as a species because it freed our hands to carry loads over long distances or make and use tools.

But evolution doesn't act on a blank canvas. It works on bodies that already exist and move through the world. Because our ancestors started on four legs and moved to the trees, we pay the price for upright walking with lower back pain and less stable joints. When we evolved bipedalism, the advantages of standing on two legs must have outweighed the disadvantages, or it wouldn't have been successful.

The questions anthropologists want to answer are: When did it happen? How did it happen? Why did it happen?

For hints, scientists turn to two places: the fossil record and our great ape cousins.

> **Great apes give us a window into our past that no other animals on Earth can provide.**

The Early Hominin Fossil Record

In the fossil record, there is evidence of bipedal features in species such as *Orrorin tugenensis* (6 million years old) and *Ardipithecus ramidus* (4.4 million years old). In remains like those of the famous "Lucy," officially named *Australopithecus afarensis* (3.2 million years old), it is clear that even after we had been standing on two legs for a while, we kept many features that came from living in the trees. That remains true today. Imagine reaching above your head to grab something out of the cupboard. That is only possible because your shoulder joint originally evolved to help us swing from branch to branch.

Still, fossils are rare, and researchers haven't found any yet that look like they may be our direct ancestors in the middle of transitioning to bipedality. So, anthropologists turn to the apes.

Great Apes

Orangutans were the first of our great ape relatives to split off from the line that would eventually become *Homo sapiens* around 13 million years ago. Today they spend more time in the trees than any other great ape and practice a form of locomotion called quadrumanous scrambling, meaning they can use their feet to grasp things, like branches, in the same way as their hands. When hanging out in trees, orangutans will often hold themselves upright by grasping high branches and standing on two legs.

Gorillas were the next apes to split from our lineage between 7 and 8 million years ago. They are the heaviest of the great apes and spend most of their time on the ground. Gorillas use a form of locomotion called knuckle-walking, moving around on all fours on their knuckles rather than the flats of their palms. They have also been observed walking upright on two legs like humans, but because their skeleton is not built to walk that way, it is slow and very energetically costly for them.

The last of the apes to split from us, and thus our closest relatives, are chimpanzees, who diverged between 5 and 6 million years ago. Chimps spend their time in the trees and on the ground, practicing both knuckle-walking and vertical tree climbing, as well as hand-over-hand swinging from branches. When the situation calls for it, they can also be observed walking bipedally on the ground, sometimes even carrying food for their young.

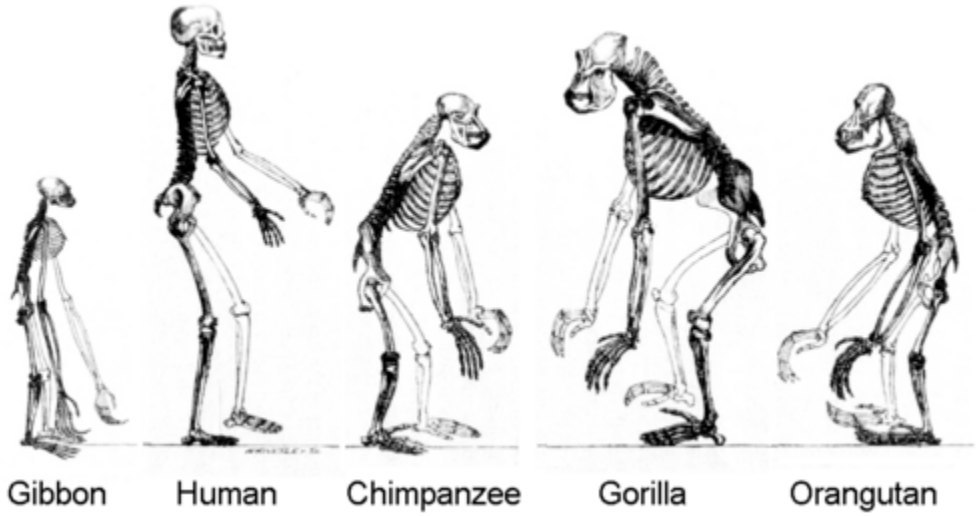


Figure 10.3.3: The physiology of the great apes can help determine when we began walking upright. (TimVickers at English Wikipedia., Public domain, via Wikimedia Commons)

Understanding Standing Up

These observations have given anthropologists a way to study the origins of bipedality in a way we just don't get from looking at fossils. Some researchers believe our ancestors started knuckle-walking on the ground before slowly moving upright sometime between when we split from gorillas and chimps. Others think we started standing upright in the trees around the time we split from orangutans, and the millions of years of selection between us and gorillas or chimps pushed those species in another evolutionary direction. Some have even suggested that it happened after our split from chimps.

Whichever argument wins the day, it's only possible to develop these lines of thinking because our ape relatives are still here to study. Great apes give us a window into our past that no other animals on Earth can provide. They offer clues about the evolution of so many things that make us human, like language, tool use, and childhood development. They aren't us, but they aren't exactly *not* us, either.

When the apes are gone, so will be an irreplaceable connection to our own past. Without them, we 7.67 billion humans will only be even more alone.

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10.4: The Evolution of Upright Walking

Rethinking Our Origins

> *"Four legs good. Two legs better"* ~ from Animal Farm[1] after the pigs adopt bipedalism to distinguish themselves from the other animals and secure their absolute control over them

Chances are that when you think of human evolution (or Google it) you'll likely get that iconic image of a chimp walking on all fours and slowly evolving into a human. As we've learned in previous lessons, this image is both misleading (evolution does not happen in a linear fashion) and incorrect (chimps are our cousins, not our ancestors), but it stems from earlier ideas about the evolution of bipedalism itself.



Figure 10.4.1: The classic "Ascent of Man" portrayal. (Image by Alexa from Pixabay)

For decades, scientists believed that humans evolved from large, knuckle-walking ancestors similar to modern chimpanzees and gorillas. This seemed logical since we share close genetic relationships with these great apes. However, the fossil evidence tells a different story. As paleoanthropologist Jeremy DeSilva notes, "not a single fossil has been found from a large, knuckle-walking ape that lived when humans, chimps, and gorillas split from their common ancestor."[2]

Instead, the fossils from this crucial time period during the Miocene (23-5.3 million years ago) come from small-bodied apes that hung by their arms and had flexible backs that supported upright posture. This evidence has revolutionized our understanding of how and why humans began walking on two legs, leading many scholars to conclude that early human ancestors never passed through a dedicated knuckle-walking phase.

A recent discovery has provided some of the most compelling evidence for this new understanding of bipedalism's origins. Found in 2016, *Danuvius guggenmosi*, a small-bodied, 11-million-year-old fossil ape from Germany, shows remarkable upright adaptations in its legs, ankles, and vertebrae. Its ankle joint is remarkably similar to both modern humans and Lucy's species, and its spine exhibits the characteristic curves that support upright posture.

This discovery, along with studies of modern gibbons, has led DeSilva to propose a revolutionary idea: that the iconic image of "the March of Progress may be backward. We didn't evolve bipedalism from a knuckle-walking ancestor. Instead, knuckle-walkers evolved from apes that were, at least occasionally, bipedal. In other words, bipedalism isn't a new locomotion at all, just an old locomotion in a new setting."[3]

What Made Bipedalism Possible: The Anatomy

Walking upright required significant changes to the human body. These anatomical adaptations tell the story of our evolutionary journey.

Position of *foramen magnum* - In bipeds, the **foramen magnum** is centralized on the bottom of the skull, closer to the teeth so that the head sits on top of the trunk of the body.

S-Shaped Spine - The spine has a characteristic S-shape curvature with **vertebrae** that increase in size and **robusticity** as you move down the spine towards the pelvis. This S-shape curvature aids in bipedalism by keeping the head centered above the pelvis to maintain balance, while the larger (lower) vertebrae help support the weight of the body. The curve at the base of the lumbar spine is unique to upright walking and helps to absorb shock while walking or running.

Shortened, broad pelvis - A biped's pelvis has a very different shape from an ape pelvis. Especially distinctive is the short ilium (hip bones). This **morphology** is an essential element of the stability of the pelvis during standing, walking, and running. The round, bowl shaped structure with robust hip bones is also important for supporting upper body weight.

Repositioned Gluteal Muscles - In chimpanzees, the lesser gluteal muscles attach to the back of the pelvis, which helps them extend their legs backward for climbing. However, this positioning makes them unstable when walking upright and requires much more energy. In humans, these muscles moved to the sides of our bodies. When we take a step, these muscles contract to keep us balanced and upright.

Length of the leg: In bipeds, the leg is generally longer relative to the arm.

Bicondylar Angle - Human femurs (thigh bones) tilt inward at the knee joint, creating what scientists call the *bicondylar angle*. Interestingly, human babies are born with straight femurs, but as they begin to walk, this signature angle develops. Chimpanzees never develop this angle, and neither do humans who for various reasons never walk.

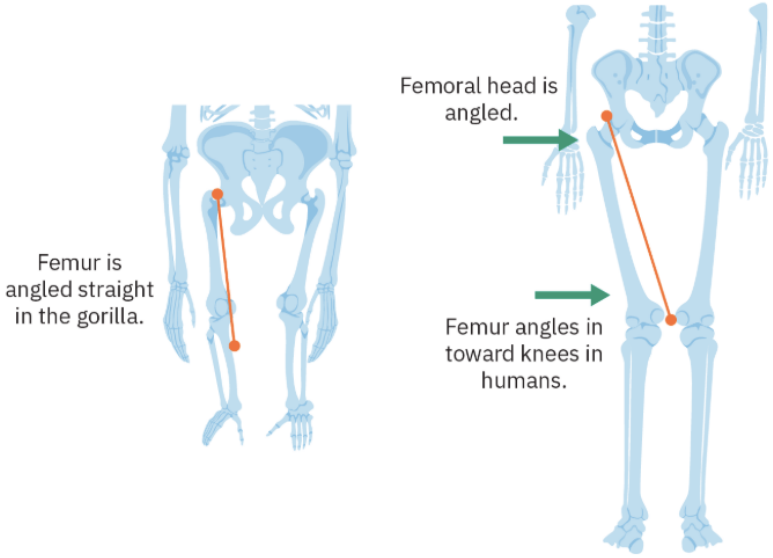


Figure 10.4.2: Comparison of femur angle in a quadruped on the left and a biped on the right. (Image attribution: Rice University, OpenStax, under CC BY 4.0 license)

Specialized Feet - Since the feet are the only part of our skeleton that actually touches the ground while walking, they show some dramatic adaptations. Bipedal feet have large, robust heels that can withstand the impact of heel strikes, rigid ankles, long Achilles tendons, an arch that acts as a spring to counteract the weight of the body pressing down on the feet, and non-grasping big toes that are short and bend upward to help propel us forward. In contrast, ape toes are long and bend downward for grasping branches.

The Environmental Context

Early bipedal ancestors lived in a challenging world and occupied an environmental niche on the edges of Africa's shrinking forests. These forest edges provided both food and safety, but venturing onto the dangerous open ground meant facing large, fierce predators. Success required caution and careful movement on two legs. Importantly, size and speed were not the driving forces behind bipedalism. Early hominins weren't trying to outrun predators or overpower competitors. Instead, bipedalism served other purposes that we're still working to fully understand. Research comparing the energy expenditure of quadrupeds versus bipeds reveals another advantage of upright walking. When tested on treadmills, chimpanzees expend double the energy that humans do for the same amount of locomotion.[4] This efficiency would have provided significant survival advantages for early hominins who needed to travel long distances while foraging.

The Social Revolution

According to DeSilva, upright walking fundamentally altered how early humans raised their children, ultimately laying the foundation for human society as we know it. With feet adapted for terrestrial walking rather than grasping, early hominin babies from established bipeds like Lucy's species could no longer cling to their mothers while they climbed into trees for safety. Meanwhile, the demands of foraging required covering vast distances to find diverse food sources. This created a dangerous vulnerability that could only be solved through cooperation. Caring for helpless infants while foraging required enlisting help from other group members. This cooperation demanded a high level of trust, reciprocation, and social coordination. Group living became essential for survival, and foraging had to be carefully timed to avoid peak predator activity. These social innovations—cooperation in food gathering and sharing, group child care, and coordinated group activities—are the fundamental qualities that define human society today. Remarkably, they all began because our ancestors walked on two legs rather than four.

An Evolving Picture

The evolution of bipedalism represents one of the most significant transitions in human evolution, yet many questions remain unanswered. Each new fossil discovery fills in pieces of the puzzle while raising new questions about our origins. What we do know is that bipedalism is not simply about anatomy or locomotion—it's about the birth of human society itself. The moment our ancestors stood upright, they began a cascade of changes that led to cooperation, trust, shared child-rearing, and ultimately, the complex social structures that define humanity today. As scientists continue to uncover new fossils and develop new analytical techniques, our understanding of this crucial evolutionary transition continues to evolve. The story of bipedalism reminds us that in science, each answer opens the door to new questions, and our understanding of human origins remains a work in progress.

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10.5: Key Terms

Absolute Dating methods: Methods used to determine the chronological age of a specimen based on a specific time scale or calendar, such as radiometric dating.

Accuracy: How close a measurement is to the true value.

Ancestral traits: Original or primitive traits retained and inherited from a distant ancestor.

Carbon 14: A radioactive isotope that decays into Nitrogen 14 with a half-life of 5730 years.

Derived traits: Evolved or mutated traits present in the most recent ancestor.

Foramen magnum: The hole at the base of the skull where the spine is attached.

Fossilization: A process where the calcium and phosphorus content of organic remains are gradually replaced by iron silica, resulting in 'stone-like' remains.

Gluteal muscles: The gluteal muscles, or glutes, are a group of three muscles which make up the gluteal region commonly known as the buttocks.

Great Rift Valley: A location in east Africa where numerous hominin fossils have been found.

Morphology: Physical shape or structure.

Mosaic evolution: Pattern of evolution in which different traits evolve at different rates and times within a lineage, creating a mixed pattern of ancestral and derived traits.

Paleoanthropologists: Biological/Physical anthropologists who specialize in the study of the human fossil record.

Potassium 40: A radioactive isotope that decays into Argon 40 with a half-life of 1.25 billion years.

Precision: How close measurements of the same item are to each other.

Radiometric methods: Techniques based on the known radioactive decay of elemental isotopes to calculate the absolute age of an item.

Relative Dating methods: Focus on determining the relative age (e.g., older versus younger) of objects, using methods including their position in a stratigraphic sequence, fluorine dating, and the use of index fossils.

Robusticity: The strength or thickness of a skeletal feature

Vertebrae: The bones that make up the spinal column.

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11: EARLY HOMININS

Learning Objectives

- Identify and describe the changing paleo-climates and paleo-environments that contributed to early hominin adaptive radiations.
- Compare and contrast early hominin species.
- Distinguish key adaptations and characteristics exhibited by early hominins.
- Assess how ideas about human evolution have changed through time.

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11.1: Lessons from Lucy

Fifty years ago, the remains of an *Australopithecus afarensis* ancestor, named "Lucy" by archaeologists, rewrote the story of human evolution.



Figure 11.1.1: Paleoanthropologist Don Johanson with a reconstruction of Lucy's skull. Julesasu, Public domain, via Wikimedia Commons

On November 24, 1974, on a survey in Hadar in the remote badlands of Ethiopia, U.S. paleoanthropologist Donald Johanson and graduate student Tom Gray found a piece of an elbow joint jutting from the dirt in a gully. It proved to be the first of 47 bones of a single individual—an early human ancestor who Johanson nicknamed "Lucy." Their discovery of her would overturn what scientists thought they knew about the evolution of our own lineage.

Lucy was a member of the species *Australopithecus afarensis*, an extinct hominin—a group that includes humans and our fossil relatives. *Australopithecus afarensis* lived from 3.8 million years ago to 2.9 million years ago in the region that is now Ethiopia, Kenya, and Tanzania. Dated to 3.2 million years ago, Lucy was the oldest and most complete human ancestor ever found at the time of her discovery.

Two features set humans apart from all other primates: big brains and standing and walking on two legs instead of four. Prior to Lucy's discovery, scientists thought that our large brains must have evolved first because all known human fossils at the time already had large brains. But Lucy stood on two feet and had a small brain, not much larger than that of a chimpanzee.

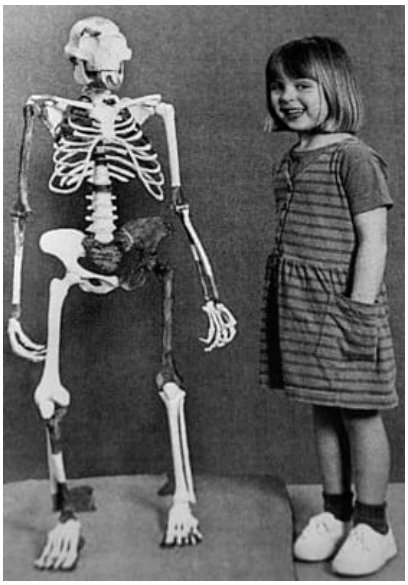


Figure 11.1.2:This picture from 1978 shows the relative size of 4-year-old Grace Latimer next to a replica of Lucy on display at the Cleveland Museum of Natural History in Ohio. *James St. John/CC BY 2.0/Flickr*

This was immediately clear when scientists reconstructed her skeleton in Cleveland, Ohio. A photographer took a picture of 4-year-old Grace Latimer—who was visiting her father, Bruce Latimer, a member of the research team—standing next to Lucy. The two were roughly the same size, providing a simple illustration of Lucy's small stature and brain. And Lucy was not a young child: Based on her teeth and bones, scientists estimated that she was fully adult when she died.

The photo also demonstrated how human Lucy was—especially her posture. Along with the 1978 discovery in Tanzania of fossilized footprint trails 3.6 million years old, made by members of her species, Lucy proved unequivocally that standing and walking upright was the first step in becoming human. In fact, large brains did not show up in our lineage until well over 1 million years after Lucy lived.

Lucy's bones show adaptations that allow for upright posture and bipedal locomotion. In particular, her femur, or upper leg bone, is angled; her spine is S-curved; and her pelvis, or hip bone, is short and bowl-shaped.

These features can also be found in modern human skeletons. They allow us, as they enabled Lucy, to stand, walk, and run on two legs without falling over—even when balanced on one foot in mid-stride.



Figure 11.1.3: A reconstruction of Lucy by artist/anthropologist John Gurche. Source: Shook, et.al. Explorations: An Open Invitation to Biological Anthropology.

In the 50 years since Lucy's discovery, her impact on scientists' understanding of human origins has been immeasurable. She has inspired paleoanthropologists to survey unexplored areas, pose new hypotheses, and develop and use novel techniques and methodologies.

Even as new fossils are discovered, Lucy remains central to modern research on human origins. As an anthropologist and paleoecologist, I know that she is still the reference point for understanding the anatomy of early human ancestors and the evolution of our own bodies. Knowledge of the human fossil record and the evolution of our lineage have exponentially increased, building on the foundation of Lucy's discovery.

Su, Denise (2024, Nov 19). *Lessons From Lucy.* *https://www.sapiens.org/biology/lucy...ensis-lessons/*

Denise Su is an associate professor in the School of Human Evolution and Social Change and a research scientist in the Institute of Human Origins at Arizona State University. Her research explores the environments in which our early ancestors lived to provide insight into how environmental factors shaped the trajectory of human evolution. Su previously was the curator of paleobotany and paleoecology and the chief academic engagement officer at the Cleveland Museum of Natural History, integrating research with public outreach and education, and leading initiatives to increase access to and diversify participation in science.

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11.2: Setting the Stage - The Paleoenvironment

How Climate Change Shaped Our Ancestors: The Environmental Pressures That Made Us Human

Today, hardly a week goes by without hearing about extreme weather events---devastating floods from massive rainstorms in Texas, wildfires in the Amazon, Canada, or California, coral reefs bleaching due to warming oceans, and rising sea levels from melting glaciers. All of these have been linked to the accelerated planetary warming caused by human activities. This makes climate change feel like a modern crisis, but our planet has been experiencing dramatic environmental shifts for millions of years. It's no coincidence that these dramatic environmental swings correspond with major bursts of evolutionary activity, including among our ancient hominin ancestors.

As paleoanthropologist, Jeremy DeSilva points out, Africa is, and always has been, vast and full of diverse habitats. Clues to dramatic changes in the African environment are hidden in the chemical signatures---namely isotopes of carbon and oxygen---found in ancient soils and fossilized teeth.[1] Part of the work of **paleoanthropologists** is to understand how the environment in which our early ancestors lived influenced their anatomy and behavior. Scientists study ancient environments, called **paleoenvironments**, to understand how global climate swings between hot-wet and cold-dry periods shaped the Earth's ecosystems millions of years ago.

To reconstruct these ancient landscapes, researchers use several detective-like techniques: they examine collections of animal fossils found at dig sites and compare them to modern animals living in similar environments today, and they analyze chemical signatures in the bones and teeth that reveal what ancient creatures ate and whether they lived in wet or dry conditions.

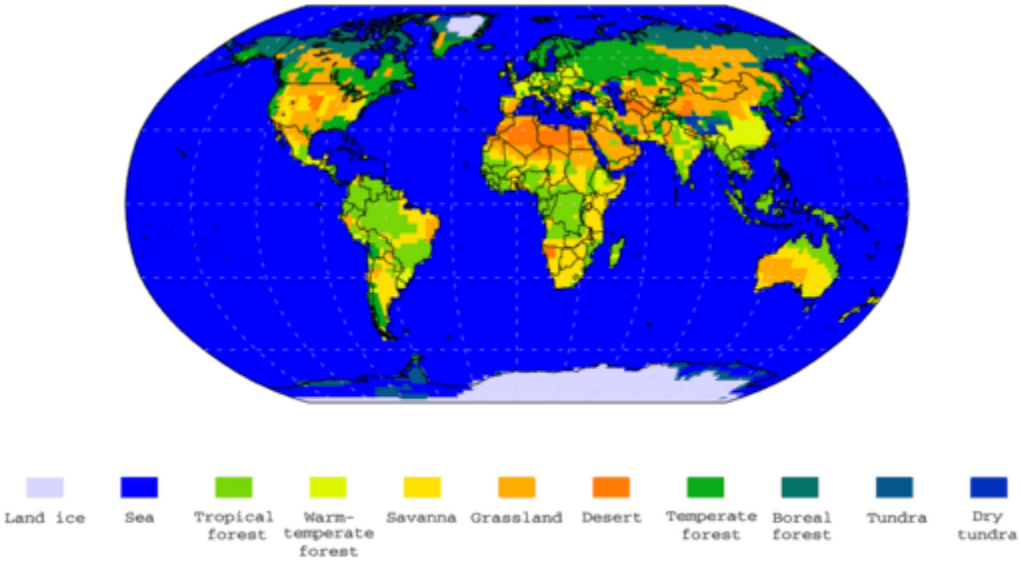


Figure 11.2.1: Pliocene Megabiome. Image by Giorgiogp2, CC BY-SA 3.0 from Wikimedia Commons

DeSilva notes that, "Starting in the **Miocene**, at least 10 to 15 million years ago, the African continent became drier and more seasonal. Climate fluctuations became more pronounced, forests in Eastern Africa gradually became fragmented, and grasslands expanded to fill the gaps between them" (2021:41-42). Using a combination of sophisticated dating techniques and chemical analyses, this research has revealed how major climate changes were the driving forces behind three crucial developments in early human evolution: our ancestors' shift to terrestrial bipedalism, their adoption of more varied diets as food sources changed, and the emergence of multiple different hominin species as groups adapted to new environmental conditions.

The Winners and Losers of Climate Change

The constantly changing paleoenvironment in Africa required increased adaptive flexibility or extinction.[2] As we'll learn in this chapter, different hominin species responded to these environmental challenges in contrasting ways. Some groups took a **specialized** approach, becoming well-adapted to a particular environment and relying heavily on limited food sources, as revealed by their distinctive skull, facial, and dental anatomy. Unfortunately, their specialization put them at a disadvantage compared to species that were more **generalized** or, in the case of the earliest members of the genus *Homo*, more innovative, and able to exploit a wider array of resources, giving them greater adaptive flexibility.

Why This Matters

Understanding how environmental pressures shaped our evolution helps paleoanthropologists reconstruct the lifeways of our earliest ancestors---what they ate, where they sought shelter and safety, what skills they needed to acquire food, and what strategies they may have used to survive in precarious landscapes. Understanding how the various hominin species that existed in the ancient past are related to each other and to us is part of a bigger, yet fascinating challenge in paleoanthropology. What we know for certain, however, is that the variation so crucial for adaptation and evolution was definitely present, giving natural selection abundant raw material for experimentation. As we'll see, this experimentation produced a **mosaic pattern** of evolution, where natural selection pieced together different traits, characteristics, and behaviors that allowed our hominin forebears to adapt to a rapidly changing world.

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1 DeSilva, J. (2021). *First Steps: How Upright Walking Made Us Human*. New York: Harper Collins.

2 deMenocal, P. B. (2014). Climate Shocks. *Scientific American*, *311*(3), 48–53.

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11.3: Pre-Australopithecines

From Forest to Grassland: The Adaptive Radiations that Mark the Dawn of Humanity

Seven million years ago, Africa was transforming. Ancient forests that had blanketed the continent for millions of years began shrinking, replaced by vast grasslands that stretched for miles across the horizon. This environmental upheaval triggered one of the most significant events in hominin evolutionary history---the emergence of the first beings that would eventually give rise to humans. But identifying these earliest ancestors is no easy task. First, we need to understand a crucial distinction between the ancestors and relatives that make up our family tree. As we've established, the admission ticket to this tree is evidence of bipedalism, but not all experiments in bipedalism led to us. To better grasp this concept, consider your own family tree:

Direct Ancestors are like your parents, grandparents, and great-grandparents—people you directly descended from. Without them, you wouldn't exist.

Close Relatives are like your aunts, uncles, and cousins—people related to you but not part of your direct family line. They're family, but you didn't descend from them.

The same principle applies to human evolution. ***Hominin ancestors*** are the species that directly led to modern humans, while ***hominin relatives*** are species that existed in the past, shared the planet with some of our ancestors, but eventually went extinct without contributing to our lineage.[1] This distinction matters because determining whether a fossil represents a direct ancestor or just a close relative is often extremely difficult. When paleoanthropologists find ancient bones and skulls, they must ask: "Could this be from a population that led directly to us, or is this from a 'cousin' species that died out?" Without genetic evidence, this becomes a significant challenge. Researchers can only rely on comparative data from the existing fossil record and living humans and apes. This task is further complicated by fragmentary fossil remains, heated scientific debates, and in some cases, unprofessional behavior that hinders scientific progress.

To understand this pivotal moment in our evolutionary story, it helps to remember that hominin evolution was not a straight line. Instead, it can be thought of as a series of **adaptive radiations**---periods when species rapidly diversify to fill new ecological niches. The late **Miocene** period (around 7-6 million years ago) gave rise to the first of these radiations, followed by a second one during the early **Pliocene** (roughly 5.3 to 2.6 million years ago). Together, these periods produced an intriguing cast of potential candidates for the title of "first hominin." These fossils continue to spark both curiosity and contested debates in the world of paleoanthropology today. Our story begins with this first adaptive radiation.

Sahelanthropus tchadensis: A Mysterious Fossil from Central Africa

The first potential candidate for earliest hominin comes from the central African country of Chad. In 2001, researchers working in a remote desert region unearthed the remains of *Sahelanthropus tchadensis*. Considering that the majority of early hominin fossils have come from eastern or southern Africa, this discovery initially seemed poised to help fill an important gap in the human fossil record.[2] The fossil itself, however, is known only from fragmentary and distorted skull, jaw, dental remains, and (as was revealed later) a femur.

The fossil evidence for Sahelanthropus presents a somewhat puzzling mix of characteristics. On one hand, it retained many **primitive traits** such as a small brain (about 350cc, which is roughly the same size as a chimp's) and a V-shaped **dental arch** typical of apes and early hominins. But in contrast, several **derived traits** have been identified, such as small canines, the absence of a **honing complex**, as well as a seemingly more centralized foramen magnum, the latter of which has been interpreted by its discoverers and others as evidence of bipedalism.

However, the story of Sahelanthropus took an unexpected turn when research on a femur which had been put aside in the species' original description has suggested that *Sahelanthropus* was not bipedal, casting doubt on one of the key pieces of evidence for its hominin status. Adding to the uncertainty, the skull's heavy distortion makes it difficult to determine the true placement and angle of the foramen magnum, leaving paleoanthropologists (and all of us), without a clear answer about how this ancient species moved through its world.

Without clear evidence of upright walking, researchers must rely on other features to determine where *Sahelanthropus* may fit (or if it fits) in our family tree. Its intriguing combination of traits such as its prominent brow ridges alongside a somewhat flattened face that hints at human-like features, creates a taxonomic puzzle that continues to challenge our understanding of these opening chapters of our human story.



Figure 11.3.1: *Sahelanthropus tchadensis* skull by Didier Descouens, CC BY-SA 4.0 via Wikimedia Commons

Dated at 6-7 million years old, *Sahelanthropus* lived at precisely the time when genetic evidence suggests the human and ape lineages were splitting from a common ancestor. This critical timing makes it the oldest *possible* human ancestor we've discovered. However, much more skeletal evidence and better access to the original fossils will be needed to definitively determine its place in human evolution.

Orrorin tugenensis: A Contender from Kenya

The second candidate vying for the title of first hominin is a 6 million year old fossil that was discovered in the Tugen Hills of Kenya in East Africa, known as *Orrorin tugenensis*. As you can see from Figure 11.3.2 below, this species is known from a small collection of fragmentary yet important bones including a partial femur (thigh bone), pieces of the upper arm bone (humerus), jaw fragments, and some teeth.

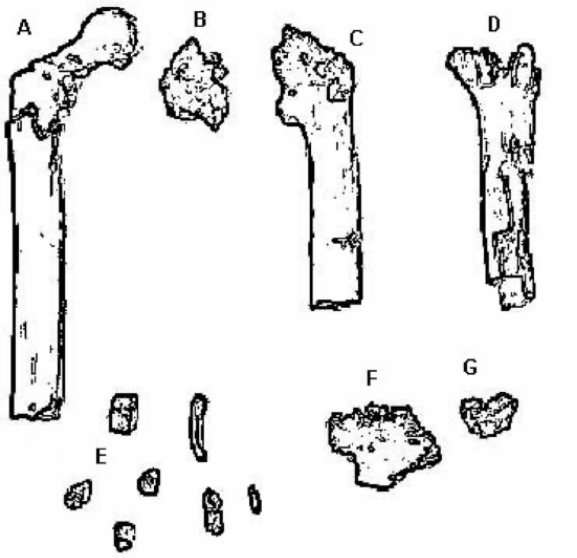


Figure 11.3.2: Fossilized remains of Orrorin. By Lucius, CC BY-SA 3.0, Wikimedia

Arguably the most important feature related to *Orrorin* is the upper portion of the femur which has a long femoral neck very similar to ours and a groove for the lesser gluteal muscles to attach. This arrangement makes it so that our hip muscles don't have to use as much energy to keep us balanced while walking on two feet. By contrast, in chimps and most other mammals, the femoral neck is short and lacks a groove. The similarity of *Orrorin's* femur to our own and to other bipedal hominins provides compelling evidence of bipedality. However, without the lower portion of the femur or any significant cranial remains to assess the positioning of the foramen magnum, researchers can't be completely certain about *Orrorin's* locomotion or its precise relationship to later hominins. This hasn't stopped its discoverers, Martin Pickford and Brigitte Senut, from making some bold claims about Orrorin's relationship to modern humans. Based on the **morphology** of its teeth, which appear more similar to ours than Lucy's do, and the structure of the femur, these scientists have suggested that Orrorin is more directly related to us than Lucy is. More fossil evidence for Orrorin will be needed to support these claims.



Figure 11.3.3: *Orrorin tugenensis* femur cast (BAR 1002'00) on display at the Smithsonian's National Museum of Natural History By Jonathan Chen - Own work, CC BY-SA 4.0, Wikimedia

The Challenge of Access and Scientific Progress

The story of Orrorin highlights a frustrating reality in paleoanthropology: the fossils remain largely inaccessible to the broader scientific community. It's not even clear where the Orrorin remains are currently stored.[3] This situation serves as a stark reminder that scientific progress depends on collaboration and open access to evidence. For our understanding of human origins to advance, the fossils documenting the very opening chapters of our evolutionary story need to be shared and examined by multiple researchers, allowing for thorough analysis and productive interpretations, even if scientists don't reach full agreement.

The cases of both *Sahelanthropus* and Orrorin illustrate one of the central challenges in paleoanthropology: determining what characteristics are most important for defining membership in the hominin lineage. Is it just bipedalism? Or are other features such as dental modifications, facial structure, and brain size important? Could it be all of the above? As new fossils from this crucial period are discovered, each find forces us to reconsider our assumptions about what it means to be on the path to humanity—and this constant questioning is exactly what good science demands.

That means that the uncertainty surrounding these early species doesn't diminish their importance. If anything, it makes them even more fascinating. Whether or not they turn out to be true hominins, these ancient species serve as humbling reminders that the story of human origins is far more complex and nuanced than we once imagined.

A Second Adaptive Radiation: A Revolutionary Discovery in the Pliocene

As Earth's climate continued to exert its relentless selective pressures, the transition from the **Miocene** (23 – 5.3 mya) to the **Pliocene** epoch (5.3 – 2.6 mya) ushered in a new chapter in human evolution. This period is marked by the appearance of a new genus: *Ardipithecus*. These pre-australopithecine species emerged from a very geologically active region—Ethiopia's Middle Awash Valley in the Afar region. Here, volcanic eruptions and tectonic shifts not only buried and preserved these ancient remains,

they've actually provided scientists with the perfect conditions for radiometric dating. The species within the *Ardipithecus* genus display an interesting **mosaic** of ape-like and human-like characteristics, with adaptations for both bipedalism and life in the trees. Given that forests still dominated the landscape during this time, this dual lifestyle makes sense. But what these discoveries revealed about the evolution of bipedalism would completely overturn decades of scientific thinking.

Meet “Ardi”: The 4.4 Million Year Old Game Changer



Figure 11.3.4: Skull Cast of *Ardipithecus ramidus* Rama, CC BY-SA 3.0 via Wikimedia Commons

The starring role in this chapter of the hominin evolutionary story belongs to *Ardipithecus ramidus*, nicknamed "Ardi," who lived 4.4 million years ago. This female skeleton represents one of the most significant fossil discoveries in paleoanthropology for several important reasons. First, the amount of evidence recovered is impressive. Scientists found more than 125 bone fragments from a single individual, plus additional bones and teeth from at least 35 other individuals. This extensive collection makes Ardi the oldest substantially complete skeleton ever discovered. Second, for a specimen of this age, the preservation is remarkably good. The skeleton includes essential bones from the hands, feet, limbs, and pelvis, as well as most of the skull and teeth. This level of completeness is unusual for fossils this old and provides researchers with detailed information about how these ancient hominins lived and moved.



Figure 11.3.5: *Ardipithecus ramidus* fossils on exhibit in the National Museum of Ethiopia by Sailko, CC BY 3.0 via Wikimedia Commons

Ardi's Anatomy: A Body Built for Two Worlds

Examining Ardi from head to toe reveals a hominin perfectly adapted for a dual existence that challenges everything we thought we knew about early human evolution:

Head and teeth – Ardi's foramen magnum sits in a central position consistent with bipedal locomotion, clear evidence she walked upright. Yet like *Sahelanthropus*, her brain remained small (around 300-350 cubic centimeters, similar to a chimp's) with a mildly projecting lower face. Her canines lacked the **honing complex** and **diastema** found in apes, and wear patterns on her teeth suggest an omnivorous diet.

Arms and Hands – Here's where Ardi becomes truly extraordinary. While her lower arm bones were extremely long compared to her upper arm bone, her hands present an evolutionary puzzle: short palm bones (like humans) combined with long, curved finger bones designed for powerful grasping (like apes). Yet her wrist bones reveal she didn't knuckle-walk like modern chimps and gorillas. Ardi's hand was neither an ape hand nor a human hand, but something entirely unique in the fossil record.

Hip and Pelvis – Ardi's pelvis was more elongated than both modern humans and later hominins like Lucy, but it clearly showed adaptations for upright walking, including wider and more **robust** hip bones that could support her weight on two legs.

Legs and feet – Her femur (thigh bone) is robust and displayed the characteristic **bicondylar angle** of a biped. Most fascinating of all, her feet were rigid enough to support upright walking, yet featured elongated toes and a fully divergent, grasping big toe—a feature not found on any other bipedal hominin.



Figure 11.3.6: An illustrated reconstruction of Ardi's full skeleton. Ori~, CC BY-SA 3.0, via Wikimedia Commons

Rewriting Human Origins

Ardi's significance extends far beyond her impressive fossil record. As the closest known hominin to the common ancestor of chimps and humans, she has forced scientists to reconsider how bipedalism evolved. For decades, researchers assumed our earliest ancestors were chimpanzee-like creatures who gradually adapted to life on the ground. Ardi proves this model wrong. Instead, the first hominins possessed a distinctive combination of arboreal and bipedal adaptations that enabled them to both walk upright on the ground and move through the trees with remarkable skill---a locomotive pattern unlike anything seen in any living primate today.

Perhaps the most revolutionary aspect of these discoveries is what they reveal about early hominin habitats. All of these ancient species lived not on the open savannas that scientists, including Charles Darwin, long believed drove human evolution, but in forested environments. This finding has fundamentally challenged the "Savanna Hypothesis"---the idea that our ancestors developed bipedalism as forests retreated and they needed to cross open grasslands.

Instead, it appears that our upright gait first evolved beneath a canopy of trees, possibly as an adaptation for moving between

patches of forest for accessing food sources in both arboreal and terrestrial environments and probably for safety as well. This revelation has required us to develop entirely new models for understanding how and why humans began walking on two legs. But as paleoanthropologist Jeremy DeSilva reminds us, “There are more fossils yet to be found and much of the human story yet to be written” (2021:86).

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1. Wood, B. (2014). Welcome to the Family. *Scientific American*, *311*(3), 42–47.

2. Lee, S. with S.Y. Yoon (2015). *Close Encounters with Humankind: A Paleoanthropologist Investigates Our Evolving Species.* New York: W.W. Norton & Co.

3. DeSilva, J. (2021). *First Steps: How Upright Walking Made Us Human.* New York: Harper Collins.

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11.4: Australopithecines

Third Adaptive Radiation: The Age of the *Australopiths*

Between 4 to 2 million years ago, numerous australopithecine species emerged to take center stage in our evolutionary story. While there are too many species to cover comprehensively—and many remain scientifically contested—they all represent variations on a revolutionary theme: upright walking. For our journey through this pivotal period, we'll focus on two of the best-known species, one from East Africa and the other from South Africa.



Figure 11.4.1: African savannah @ Masai Mara by Leo Li CC BY 2.0 via Wikimedia Commons

During this time, Africa was once again undergoing dramatic environmental changes. Forests were shrinking, and vast grasslands were expanding across the continent. In response to these pressures, australopithecine species had to develop new strategies for surviving in this transformed landscape. While this group of hominins are definitely not what we would consider to be human, they weren't apes either. Instead, they represent something entirely new and it's best to understand them on their own adaptive terms rather than thinking of them as a less advanced form of human or a more advanced form of ape.

> ***"Lucy is the starting point for all we think we know about human evolution"*** **– Paleoanthropologist Jeremy DeSilva**

Australopithecus afarensis: The Poster Child of the Savanna Hypothesis



Figure 11.4.2: Reconstruction of *Australopithecus afarensis* “Lucy” skull. Bone Clones, CC BY-SA 3.0 via Wikimedia Commons

Fossil Evidence for Australopithecus afarensis

We've already learned about the famous Lucy fossil and the impact she's had in the field of paleoanthropology. But even more fossils of *Aus. afarensis* have been recovered from multiple sites across the Afar region of Ethiopia, spanning approximately 3.9 to 2.9 million years ago. Just two years after discovering Lucy in 1974, Johanson's team made another remarkable find at a nearby site in Ethiopia. This site yielded the fossilized remains of at least 13 individuals of *Aus. afarensis*, known as the “First Family.” The remains included individuals of different ages—from infants to adults—providing unprecedented insight into the physical variation and development within the species. The individuals within this group reveal a high degree of sexual dimorphism in which males were much larger than females and their skull features more robust, including the presence of a **sagittal crest**.

Anatomy of a Revolution: Lucy’s Bipedal Body

To understand how Lucy’s body was built for walking, let’s take a tour through some key skeletal structures.

Skull – At the base of Lucy’s skull was a centrally positioned foramen magnum. This kept her head balanced and facing forward as she walked upright.

Spine – Lucy’s spine has an S-shape curve, similar to our own, that helps balance the torso and head over the hips.

Pelvis – Perhaps most impressive was Lucy’s pelvis. Short and wide with robust hip bones positioned on the sides of her body, it was perfectly designed to keep her upright and balanced on two legs. Her hip muscles could now support her entire body weight while walking.



Figure 11.4.3: A reconstruction of Lucy's pelvis on display at the National Museum of Ethiopia by Ji-Elle, CC BY-SA 3.0 via Wikimedia Commons

Femur – Lucy's femur exhibits the **bicondylar angle** found only in bipeds, bringing her knees closer together under her center of gravity to make walking much more efficient.

Feet – A set of fossilized footprints found at Laetoli, Tanzania, tell an amazing story. These 3.6-million-year-old tracks show Lucy's species walking across volcanic ash, leaving behind evidence that their foot strikes were remarkably similar to ours. They had large heel bones to absorb the impact of each step, and while their toes were longer and more curved than ours, they still pushed off the ground in a distinctly human-like way. In addition, her ankle bones look like a smaller version of our own.

Surviving on the Savanna

Standing just three and half to four feet tall and weighing in at a mere sixty pounds, Lucy was tiny by our standards (recall the photo of her skeleton next to the young girl). Her brain was only slightly larger than a chimpanzee's, and she likely shared many behaviors with our primate cousins, including simple tool use. Based on analysis of her teeth, Lucy matured much faster than modern humans. She is estimated to have been in her late teens when she died—already a full grown adult by australopithecine standards, with her wisdom teeth fully erupted.

As a small-bodied, two-legged hominin, Lucy and her kind faced a world full of danger. The expanding grasslands of the African savanna were teeming with giant and hungry predators: saber-toothed cats and massive hyenas prowled the landscape while enormous crocodiles lurked near water sources. Evidence of this dangerous world is literally written in Lucy's bones—her pelvis bears the indentations of two bite marks, showing that a scavenger had gotten to her remains before they were buried in the mud of an ancient lakeshore (DeSilva 2021: 50-51).



Figure 11.4.4: Juvenile *Aus. afarensis* found in 2002 called “Selam” or “Lucy’s child”(DIK-1/1) model reconstruction at the California Academy of Sciences by Ryan Schwark, CC0 in the public domain via Wikimedia Commons

As bipeds, Lucy and her kind faced a cruel irony: they were among the slowest-moving animals on the landscape, making them extremely vulnerable to predation. How did they survive? The answer likely lies in their behavior. These early hominins probably lived in groups for safety, spending their days cautiously foraging on the ground for anything edible, then retreating to the safety of the trees at night. This activity pattern gave them a crucial advantage in the deadly game of survival since most predators prefer to rest in the shade during the hottest time of the day, conserving their energy for hunting at dusk, dawn, and the dead of night.

Australopithecus africanus - The First Australopithecine Ever Discovered

While Lucy may be the most famous australopithecine, she wasn’t the first in this genus to be discovered. That honor belongs to a different species found much earlier and much farther south on the African continent. In 1924, anatomist Raymond Dart was examining a crate of rocks from a South African mining operation from the town of Taung when he made a discovery that would reshape the understanding of human evolution at that time. Hidden among the rocks was a small skull belonging to a child. Known as the Taung Child, this fossil represents the first australopithecine known to science: *Australopithecus africanus*. Thanks to an incredible stroke of luck, the skull preserved an endocast—a fossilized replica of the child’s brain, complete with all of the detailed patterns of its cranial arteries and the folds and fissures of the brain itself.



Figure 11.4.5: Replica of the Taung Child fossil by Guérin Nicolas, CC BY-SA 3.0 via Wikimedia Commons

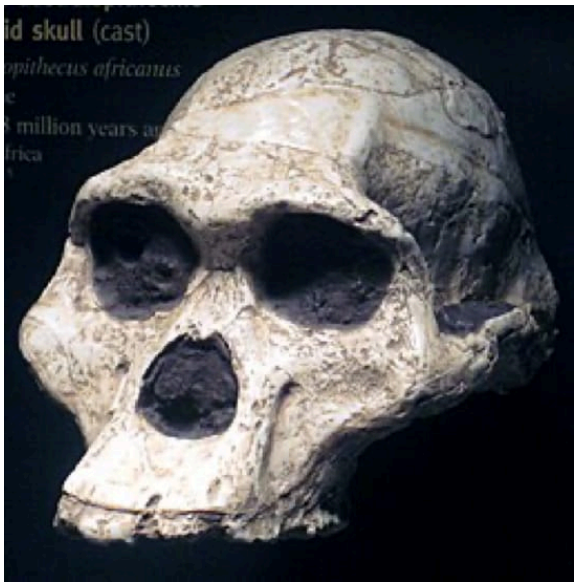


Figure 11.4.6: Replica of adult *Australopithecus africanus* found at Sterkfontein by James St. John, CC BY 2.0 via Wikimedia Commons

As an expert in brain anatomy, Dart could see something intriguing. Although the Taung Child's brain was about the size of an adult ape's, its structure was organized much more like a human's. And when he turned the skull over, the tell-tale feature of the centrally positioned foramen magnum told him he was holding the skull of a human ancestor. Further discoveries at the South African cave site of Sterkfontein confirmed what Dart was already suspecting. Bones from the spinal column, pelvis, and knees were all consistent with those of a bipedal hominin (DeSilva 2021:9-10).

Compared to Lucy's kind, *africanus* shows some interesting differences. They had a relatively larger brain (around 400-500 cubic centimeters), smaller canine teeth, and more rounded skulls. Yet they still retained some **primitive features** like sloping faces and curved finger bones (Warren, et. al).

The discovery of the Taung Child in 1924 forced the scientific community to confront both the biases in the fossil record and their own assumptions about how human evolution unfolded. Before this find, all known human fossils came from Europe and Asia, belonged to members of our own genus *Homo*, and had relatively large brains. This limited evidence had led scientists to assume that our defining feature—large brains—came first in human evolution, with upright walking following later. Everything about *africanus* shattered this prevailing model. Here was solid proof that our ancestors were walking upright millions of years before large-brained hominins evolved. This discovery fundamentally shifted the focus of human evolution research to Africa—exactly where Darwin had always predicted our origins to lie.

The Legacy of the Australopithecines

The age of the australopiths represents an important chapter in our evolutionary history. Whether they are our direct ancestors or relatives on side branches, they all belong to the human family tree. Some of these evolutionary lineages eventually became extinct, while others continued toward the lineage that would produce modern humans. It is with these amazingly successful early human survivalists that the first steps toward becoming human truly began.

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Warren, K., et. Al. (2023). Chapter 9: Early Hominins. In Shook, et. Al. (Eds.), *Explorations: An Open Invitation to Biological Anthropology, 2nd Edition*. Licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

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11.5: The Robust Hominins

Meet the Paranthropines

Imagine finding a skull so large and sturdy that scientists nicknamed it "Nutcracker Man." This discovery isn't from science fiction—it's a real chapter in human evolution. Around 2.7 million years ago, a group of early human relatives called **paranthropines** lived in Africa. These hominins belonged to the **genus Paranthropus** and were our distant cousins, but they evolved very differently from our direct ancestors. What made paranthropines unique? They had incredibly powerful jaws and massive chewing muscles that could process foods tough enough to break modern human teeth. Their skulls were built like biological nutcrackers, with thick bones and prominent ridges where their jaw muscles attached. While other early hominins were learning to make tools and eating more varied diets, paranthropines specialized in eating hard, fibrous plants like roots, seeds, nuts, and grasses. This **robust** build was an impressive adaptation that worked well for more than a million years. Paranthropines lived alongside other early human ancestors, including australopithecines and the first members of our own genus, *Homo*. However, their extreme specialization eventually became a disadvantage. As Africa's climate changed and food sources shifted, these "nutcracker" hominins couldn't adapt quickly enough. Their hyper-specialized lifestyle, once their greatest strength, led to their extinction while more flexible hominins survived and evolved into modern humans.

Paranthropus aethiopicus: The Pioneer

When: 2.7 to 2.3 million years ago
Where: East Africa

The story begins with *Paranthropus aethiopicus*, the earliest member of this robust lineage. This hominin had distinctive skull features that differed significantly from our own. They possessed prominent brow ridges, wide cheekbones that housed large chewing muscles, and a bony ridge that looks like a mohawk (called a **sagittal crest**) running along the top of the skull where powerful jaw muscles attached. However, their teeth tell the most important part of their story. *P. aethiopicus* had unusually large, flat premolars and molars that functioned like natural grinding surfaces. These dental adaptations, combined with their skull structure, were specialized for processing tough plant foods that other hominins couldn't efficiently eat. Everything about their head and face anatomy was adapted for this challenging diet.

The famous "Black Skull" (specimen KNM-WT 17000) gives us our best look at this early robust species, showing us just how different the paranthropine experiment was from the beginning.



Figure 11.5.1:Model of *Paranthropus aethiopicus* (the “Black Skull”) at the Natural History Museum, London by Nrkpan, CC BY-SA 3.0 via Wikimedia Commons

Paranthropus boisei: “Nutcracker Man”

When: 2.3 to 1.2 million years ago
Where: East Africa (Tanzania's Olduvai Gorge)

In 1959, archaeologist Mary Leakey made an important discovery that contributed to our understanding of this branch on the family tree. Working with her husband Louis Leakey in Tanzania's Olduvai Gorge, she uncovered a well-preserved skull with notably robust features. The Leakeys initially thought they had found the toolmaker responsible for the stone tools scattered throughout their excavation site. However, closer examination of the skull's teeth, face, and jaw structure revealed a different story about this hominin's lifestyle and capabilities.



Figure 11.5.2: Cast of "Nutcracker Man" (*Paranthropus boisei*) skull by Rama, CC BY-SA 3.0 FR via Wikimedia Commons

What they had discovered was *Paranthropus boisei*, nicknamed "Nutcracker Man." This hominin had no need for stone tools because it functioned like a living tool, equipped with specialized anatomy that could process foods other hominins couldn't eat. Their jaws were powerful enough to crack open nuts and seeds. The hyper-robust features associated with *P. boisei* indicate that as environments became more challenging and food sources tougher, this species adapted by developing increasingly powerful food-processing capabilities. Nuts, roots, tubers, seeds, and tough grasses were all part of Nutcracker Man's diet, processed by what functioned essentially as biological grinding equipment. The skull's anatomy clearly reflects this specialization. *P. boisei* had prominent brow ridges, an unusually wide face that housed large chewing muscles, heavily worn molars and premolars, a substantial jaw, and a distinctive sagittal crest running along the skull's top. This bony ridge served as an attachment point for some of the most powerful chewing muscles found in any hominin species.

Paranthropus robustus: The South African specialist

When: 2.0 to 1.5 million years ago
Where: South Africa (Swartkrans, Kromdraii, and Drimolen cave sites)

In 1936, scientists made a remarkable discovery, this time in the cave systems of South Africa. *Paranthropus robustus* shares the family resemblance with its East African cousins—the big face, large premolars, and well-developed sagittal crest—but took specialization to an even greater extreme.



Figure 11.5.3: Cast of *Paranthropus robustus* at the Beijing Museum of Natural History, China by Bjoertvedt, CC BY-SA 4.0 via Wikimedia Commons

Here's where the story gets particularly interesting: advanced chemical analysis of these fossils has revealed exactly what *P. robustus* was eating. Using stable carbon isotope analysis (a technique that can identify what plants an animal consumed by analyzing the chemical signatures left in their bones), scientists discovered that this species had committed almost entirely to eating low-quality savanna grasses and tough vegetation. This wasn't just a preference—it was an ecological niche that required extreme specialization. These foods were so fibrous and nutrient-poor that processing them demanded constant, powerful chewing. *P. robustus* had essentially become a biological lawn mower, perfectly adapted to extract nutrition from plants that other animals couldn't efficiently digest.

The Dead End: Why Specialization Failed

The robust hominins teach us an important lesson about evolution: extreme specialization can limit survival options. While the paranthropines were developing their role as specialized plant processors, other hominins were taking a different evolutionary approach. Some, like early *Homo* species, were making and using stone tools, which allowed them to access a much wider variety of foods without requiring major anatomical changes. Others, like the more generalized australopithecines, maintained more flexible dietary adaptations, with less specialized teeth and jaw structures that could handle both plant and animal foods as opportunities arose.

This contrast highlights a key evolutionary trade-off. Instead of evolving massive jaws and large teeth, tool-using hominins could access meat, marrow, and other nutrient-rich foods that required less specialized anatomy. Similarly, the more generalized australopithecines could shift their diets seasonally or when environmental conditions changed, eating fruits when available, falling back on roots and tubers during dry periods, cracking nuts with stones, and occasionally scavenging meat—all without the anatomical constraints that limited the paranthropines.

As climate continued to change and habitats shifted, both the neighboring tool-making hominins and the australopithecines could modify their behavior and diet relatively quickly. The robust paranthropines, however, were constrained by their specialized anatomy and had fewer adaptive options. While their cousins could explore new food sources or move to different habitats, the paranthropines remained tied to environments that could support their high-fiber, plant-based diet. They were gradually displaced from their ecological niches and eventually became extinct---a true evolutionary dead end.

Despite their extinction, these species remain part of our extended family tree. They shared the key hominin characteristic of a centrally positioned foramen magnum which indicates upright walking. This makes them our relatives in human evolution, even though they were not our direct ancestors.

The Bigger Picture

The robust hominins represent just a fraction of the incredible diversity that characterized early hominin evolution. Dozens of other fossil species populated the African landscape during this crucial period, each representing different evolutionary experiments and adaptations to changing environments. What's remarkable is how much variation existed among these early human relatives. This diversity gave natural selection an enormous biological database to work with, allowing evolution to test different strategies for survival in challenging and changing environments.

We still don't have a complete picture of exactly how all these species relate to each other, or which lineages eventually led to modern humans. Every new fossil discovery adds another piece to this ancient puzzle, sometimes confirming our theories and sometimes forcing us to completely reconsider the story of human evolution. The detective work continues, and with each new find, we get closer to understanding the full drama of our origins—including the fascinating cast of characters such as the dead ends like the paranthropines that remind us that evolution is not a straight line toward humans, but a complex tree with many branches, some of which lead nowhere at all.

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1. deMenocal, P. B. (2014). Climate Shocks. *Scientific American*, *311*(3), 48–53.

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11.6: Key Terms

Adaptive radiation – process in which a lineage rapidly diversifies with the newly formed lineages evolving different adaptations

Ancestor - hominins that are considered to be directly related to humans

Australopiths - (short for australopithecines) hominin species that belong to the genus *Australopithecus*

Bicondylar angle – inward angling of the femur (thigh bone) towards the knee joint that transfers weight from the hips to the knees and down into the feet

Dental arch - the curved shape formed by the rows of teeth in either the upper (maxillary) or lower (mandibular) jaw

Derived traits - Newly evolved traits that differ from those seen in the ancestor.

Generalist - A species that can thrive in a wide variety of habitats and can have a varied diet.

Honing (P3) complex - a specific dental arrangement in some primates, particularly apes and baboons, where large, pointed canine teeth are sharpened by a rubbing action against the lower third premolar as the jaw opens and closes

Miocene - Period in the geologic time scale that extends from 23 to 5.3 million years ago

Morphological – relating to the physical shape or structure

Mosaic pattern of evolution – pattern of evolutionary change where various body parts or functions evolve rapidly while others remain stable, resulting in a mix or “mosaic” of ancestral and derived traits

Paleoanthropologists – anthropologists who study human evolution through the analysis of fossil remains and archaeological evidence

Paleoenvironment – ancient environment of the Earth’s past including climates, ecosystems, and geological conditions

Paranthropines - robutst hominin species that belong to the genus *Paranthropus*

Phylogeny – evolutionary family tree

Pliocene - Period in the geologic time scale that extends from 5.3 to 2.6 million years ago

Pre-Austrlopithecines - early hominin species that pre-date the hominins belonging to the genus *Australopithecus*

Primitive (ancestral) trait – a trait that has been inherited from a distant ancestor

Relative - hominins that are part of the human family tree and related to us by virtue of their bipedalism, but are not our direct ancestors

Robust - In the context of bones, "robust" generally refers to bones that are strong and thick, reflective of load bearing

Sagittal crest – crest of bone along the midline of the skull for muscle attachment

Specialist - A specialist species can thrive only in a narrow range of environmental conditions or has a limited diet.

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12.1: Defining the Genus Homo

The Big Questions About Human Origins

When did the first humans walk the earth? When did our ancestors develop speech and language? Who were our earliest relatives? What path did human evolution take to lead to us today? These questions lie at the heart of anthropology because understanding what makes us human is central to the field. Ever since scientists discovered that extinct human species once existed, they've debated a crucial question: which of these ancient species were "human enough" to be classified in our genus, *Homo*?

Today, *Homo sapiens* are the only living species in the genus *Homo*. But in the past, many other human species lived on Earth. We only know about these species through the fossils and the tools they left behind. Sometimes, multiple human species even lived at the same time in different parts of the world. In the previous chapter, we learned how walking upright (bipedalism) separated the earliest human ancestors from other primates. However, all *Homo* species walked upright, so scientists need to look at other features to tell them apart. The skull is particularly useful because it's unique to each species so researchers examine details like the shape of the brow ridge above the eyes, tooth characteristics, and brain case size.

Beyond Bones: Studying Ancient Lifestyles

Some researchers go beyond studying skulls and bones to understand how our ancestors lived. One of these researchers is Dr. Briana Pobiner at the Smithsonian Institution, who acts like a "dietary detective." She studies ancient meal remains to identify uniquely human traits by examining:

- How bones were broken
- What types of puncture marks appear on bones
- Where these marks are located

This detective work helps her figure out what animals our ancestors ate and how they obtained their food.

Dietary Detective: Dr. Briana Pobiner

Meet Briana Pobiner -- human origins researcher and educator at the Smithsonian's National Museum of Natural History in Washington, D.C. Briana tells what it's like to be a human evolution expert, why it matters, and how she got here. Digging up early human and animal remains from the field in Africa, performing examination and publishing research about her findings, then enticing and educating the public about the implications are all in a week's work for Dr. Pobiner.

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

Smithsonian Institution. (2011). *Dietary Detective: Smithsonian Scientist Briana Pobiner*. [Video]. YouTube. https://www.youtube.com/watch?v=VYSw0EWwNhw&t=79s

What Makes a Species "Human"?

When biologists group species into the same genus, they consider three main factors:

1. **Physical characteristics** (morphology)
2. **Evidence of recent common ancestry**
3. **Adaptive strategy** (how they used their environment)

Scientists don't always agree on which factor is most important or how to interpret specific fossils. However, most agree that species classified as *Homo* should share these key characteristics:

- **Relatively large brain size** (indicating high intelligence)
- **Smaller, flatter face**
- **Smaller jaws and teeth**
- **Increased reliance on culture**, especially stone tools, to survive in diverse environments

Some researchers might also include larger overall body size and different limb proportions (longer legs, shorter arms) in this list.

The Challenge of Incomplete Evidence

While these criteria seem straightforward, applying them to actual fossils is complicated for several reasons:

Incomplete fossils: Many fossil specimens from this time period are fragmentary and poorly preserved, making it difficult to get the full picture.

High variability: Early *Homo* fossils show surprising diversity in brain size, facial features, teeth, and body size. Scientists are still debating how to make sense of this variation.

Mosaic evolution: The characteristics that define our genus didn't appear all at once in a single species. Instead, they developed patchily with different traits appearing in different species at different times and places. Think of it like a mosaic artwork where individual pieces come together gradually to form the complete picture.

Because of these challenges, scientists still debate how to classify some of the earliest *Homo* fossils. With that in mind, we'll focus more on the general trends that begin to appear in the genus, and one of the most important is related not to physical features, but behavioral (cultural) adaptations.

A Cultural Revolution Begins

The earliest *Homo* species appeared nearly 2.6 million years ago, living alongside other human relatives from the genera *Australopithecus* and *Paranthropus*. Like these relatives, *Homo* species walked upright. However, they stood apart because of two key features:

1. **Relatively large brain cases** compared to their body size
2. **Consistent association with recognizable tools and cultural artifacts**

Culture became the defining feature that separated *Homo* from earlier human relatives. While evidence of opportunistic scavenging exists from a site in Kenya where animal bones with cut marks date back 3.3 million years (within the *Australopithecine* range), early hominin sites lack a consistent record of stone tool use. However, with the emergence of the genus *Homo*, animal bone assemblages show a dramatic shift. These sites reveal clear evidence of systematic stone tool use alongside manufacturing debris from toolmaking itself. This marked a crucial turning point for *Homo* species as culture became central to survival. Rather than merely adapting to their environment, these hominins began using cultural innovations to actively shape their evolutionary trajectory in entirely new directions.

Piecing Together the Human Story

In this chapter, we'll explore the origin and evolution of our genus through several approaches:

1. **Environmental context:** We'll examine the Pleistocene epoch conditions in which the genus *Homo* hominins evolved
2. **Fossil evidence:** We'll study the two main early *Homo* species: *Homo habilis* and *Homo erectus*
3. **Behavioral reconstruction:** We'll use fossils and archaeological sites to understand how early *Homo* lived, including their:
    - Tool-making techniques

    - Food-gathering practices
    - Migration patterns
4. **Adaptive strategies:** We'll consider how this adaptive flexibility set our ancestors on the evolutionary path that eventually led to modern humans

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12.2: The Climate Context

The Pleistocene Challenge: Surviving Ice Age Climate Swings

To understand what forces shaped our early human evolution, we need to look at the climate conditions our ancestors faced. Our early *Homo* ancestors lived during a time period called the Pleistocene epoch, which lasted from 2.6 million years ago to 11,000 years ago. This period brought major changes to Earth's environment and is commonly known as the Ice Age.

When people hear "Ice Age," they usually picture a world covered in glaciers and filled with woolly mammoths, essentially, a planet that was cold everywhere. However, this picture isn't accurate. Instead of being constantly cold, the climate became much more unpredictable. The Earth's climate swung back and forth between two extremes: warm and wet periods (called interglacial periods) and cold and dry periods (called glacial periods). These climate swings happened because of changes in Earth's orbit around the sun.

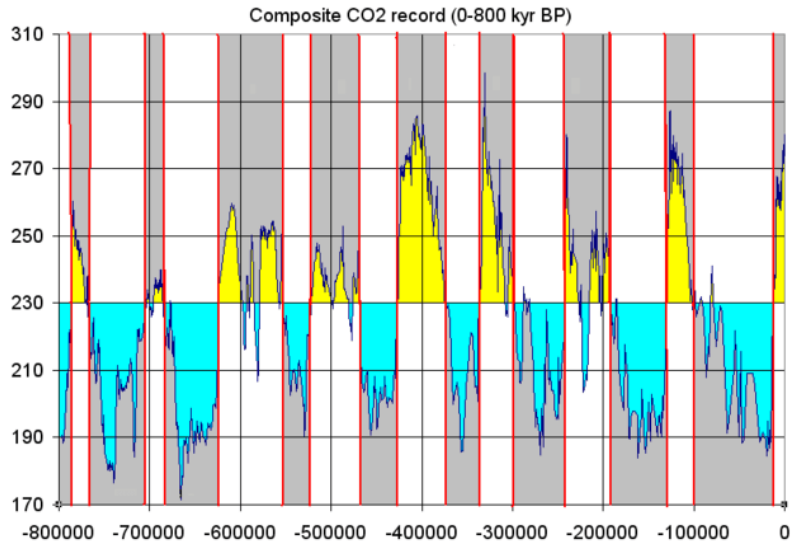


Figure 12.2.1: Graph depicting the typical glacial and inter-glacial cycles of the Pleistocene epoch over last 800,000 years as measured by concentration of CO2 (in part per million on the left). Higher CO2 concentrations, represent the interglacial periods in yellow while lower CO2 concentrations, represent the glacial periods in blue. By Tomruen - Data from ncdc.noaa.gov, Composite CO2 record (0-800 kyr BP), marked up with 230 ppm transition between glacial and interglacial periods., CC BY-SA 3.0 via Wikipedia

And, as Figure 12.2.2 below shows, these climate cycles followed a pattern. During the early Pleistocene, each cycle lasted about 41,000 years on average. Then, starting around 1.25 million years ago, the cycles became longer—about 100,000 years each. Because factors like mountain ranges, wind patterns, ocean currents, and volcanic eruptions also affect climate, different regions around the world experienced these changes differently.

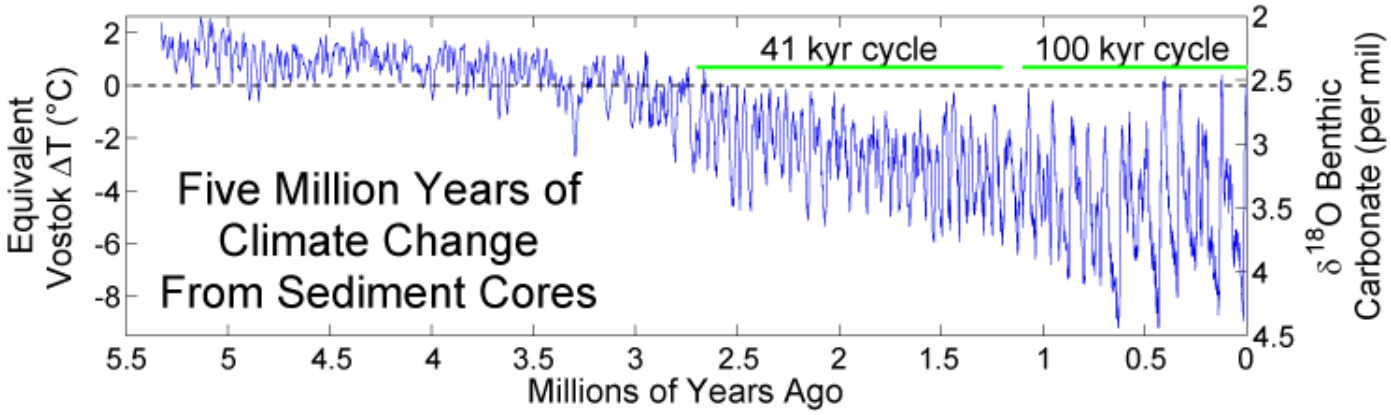


Figure 12.2.2: Temperature estimates during the last five million years, extrapolated from deep-sea core data. Lower temperatures and increased temperature oscillations start at 2.6 million years ago. Glacial/interglacial cycles during the early part of the epoch are shorter, each averaging about 41,000 years. Credit: Five Myr Climate Change by Dragons flight (Robert A. Rohde), based on data from Lisiechi and Raymo (2005), is under a CC BY-SA 3.0 License.

Understanding ancient geography and climate helps us figure out how our ancestors moved around the world and what limitations they faced. When the Earth cooled down during glacial periods, ocean levels dropped because more water was frozen in glaciers. This exposed land that is normally underwater, creating bridges between continents and islands. During these cold periods, the large Indonesian islands of Sumatra, Java, and Borneo were connected to Southeast Asia by land. New Guinea was connected to Australia. A land bridge linked Britain to the rest of Europe, and a frozen, treeless area called Beringia connected northern Asia to Alaska. At the same time, glaciation made some northern areas too harsh for humans to live in. For example, we have evidence that early human species lived in Britain 950,000 years ago, but they didn't stay there continuously. These early humans likely died out or had to leave the region when glacial periods made survival impossible.

In Africa, climate research shows that grasslands expanded and shrank repeatedly during this time period, though overall they grew larger over the long term (deMenocal 2014).



Figure 12.2.3: A savanna grassland in East Africa. Habitats such as this were becoming increasingly common during the Pleistocene. Credit: Savanna grasslands of East Africa by International Livestock Research Institute (ILRI)/Elsworth is under a CC BY-NC-SA 2.0 License.

By studying fossils, scientists have been able to recreate what animal communities looked like during the Pleistocene and understand how climate change affected them. In Africa, the number of grazing animals like antelopes increased. Even though Africa and Eurasia are connected by land, the Sahara Desert and the mountains of North Africa create natural barriers that make crossing difficult. However, the fossil record shows that at various times, animals moved back and forth between these continents. During the early Pleistocene, African animals like baboons, hippos, antelopes, and African buffalo migrated out of Africa into Eurasia during dry periods (Belmaker 2010).

This constantly changing environment created both challenges and opportunities for our ancestors. One strategy some early humans used was to specialize in eating the new types of plants growing in these changing landscapes. The robust hominins (discussed in Chapter 11) likely developed their large back teeth with thick enamel to handle this specialized diet.

Members of the genus *Homo* chose a different path. When faced with Africa's unstable climate and shifting landscapes, they evolved larger brains. These bigger brains allowed them to solve problems through culture and technology, such as making stone tools that opened up new ways to find food. This strategy of being flexible and adaptable served them well during these unpredictable times. It led to important innovations like eating more meat, hunting together in groups, and successfully moving into new environments outside of Africa.

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12.3: Homo habilis - The Earliest Member of our Genus

The Discovery That Defined a Genus

The story of *Homo habilis* begins in the early 1960s at one of paleoanthropology's most famous sites: Olduvai Gorge in Tanzania. The Leakey family had been excavating this remote corner of East Africa since the 1930s, already uncovering important hominin fossils including the robust *Paranthropus boisei* (nicknamed "Nutcracker Man"). It was their 20-year-old son Jonathan who made the pivotal discovery—fragments of a lower jaw, pieces of skull, and hand bones belonging to a juvenile individual.

When Louis and Mary Leakey examined these 1.75-million-year-old remains, they realized they had found something unprecedented. This wasn't just another australopithecine like "Lucy." The teeth were smaller and less bulky, the skull more rounded, and most intriguingly, the hand bones showed clear evidence of a precision grip, the same kind of grip you use to hold a pen or pencil. The Leakeys recognized they were looking at a new species that seemed to bridge the gap between the more ape-like australopithecines and modern humans. They named it *Homo habilis*, meaning "handy man."

Homo habilis represented an interesting new variation on the hominin theme. While their bodies remained surprisingly similar to earlier australopithecines with slightly longer arms than legs and still relatively small body build, their heads told a different story. Their brains were slightly larger, averaging 650 cubic centimeters (cc) compared to *Australopithecines* with less than 500 cc. Additionally, their faces were less **prognathic** (protruding forward), giving them a slightly more human-like appearance.

The Stone Age Begins

The real game-changer, however, wasn't their anatomy it was their behavior. *Homo habilis* became the first hominins to systematically manufacture stone tools, launching what paleoanthropologists call the **Oldowan** tool industry. Named after Olduvai Gorge where these tools were first discovered, the Oldowan period spans approximately 2.5 to 1.6 million years ago.

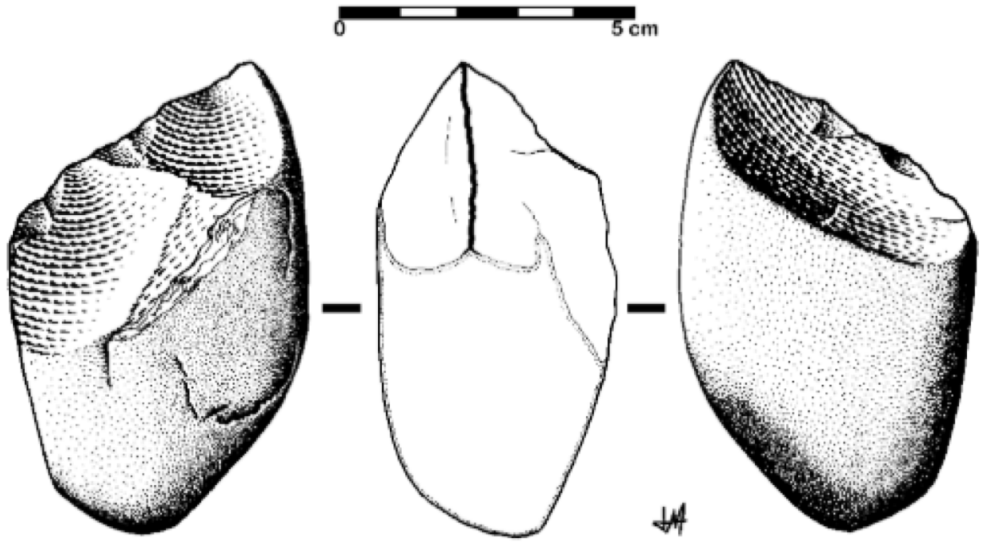


Figure 12.3.1: Drawing of an Oldowan-style tool. This drawing shows a chopper; the flakes removed from the cores functioned as cutting tools. Credit: Chopping tool by José-Manuel Benito Álvarez is under a CC BY-SA 2.5 License.

The tools of this industry are described as “flake and chopper” tools which were basically choppers consisting of stone cobbles with a few flakes struck off them (Figure 12.3.1). To a casual observer, these tools might not look much different from randomly broken rocks. However, they are harder to make than their crude appearance suggests. The rock selected as the core must be struck by the rock serving as a hammerstone at just the right angle so that one or more flat flakes are removed. This requires selecting rocks that will fracture predictably instead of chunking, as well as the ability to plan ahead and envision the steps needed to create the finished product. The process leaves both the core and the flakes with sharp cutting edges that can be used

for a variety of purposes.

A Dietary Revolution

What were these early humans doing with these tools? The evidence points to an important shift in diet and lifestyle. Animal bones found at Oldowan sites tell a fascinating story—they're covered in cut marks and show signs of being deliberately cracked open to extract the nutrient-rich marrow inside. But here's where the story gets really interesting: these bones come from animals ranging from small antelopes to massive elephants and wildebeest. Could small-bodied *Homo habilis* really have acquired such large prey without any sophisticated hunting tools? The answer likely lies in scavenging rather than hunting. Relying on their “handy” and easily transportable tools, along with their keen sense of the environment, and their place within it, *Homo habilis* could essentially outsmart the competition.

Paleoanthropologist Robert Blumenschine has studied modern African predators and scavengers to understand how this might have worked. When lions finish a kill, other scavengers immediately swarm the carcass. By the time the comparatively slow-moving, small-bodied hominins arrived, most of the meat would be gone. But here's the clever part: while other scavengers fought over scraps, *Homo habilis* would have been able to use their stone tools to crack open the long bones and access the calorie-dense marrow that the other scavengers couldn’t get to (Blumenschine et al. 1987).

Stone tools served purposes beyond meat processing. Microscopic analysis of tool wear patterns reveals they were also used to process various plant materials—wood, roots, tubers, seeds, and stems (Lemorini et al. 2014). *Homo habilis* had essentially invented the world's first multi-purpose tool, dramatically expanding their dietary options and ecological niche. This adaptive flexibility would become a defining characteristic of the entire Homo lineage.

As mentioned in section 12.1, the 3.3-million-year-old stone tools from the site in Kenya were made by earlier hominin species than *Homo*. However, stone tools become more frequent at sites dating to about 2 million years ago, the time of *Homo habilis* (Roche et al. 2009). This suggests that these hominins were increasingly reliant on stone tools to make a living.

Confusion and Controversy: The Challenges of Interpreting and Classifying Fossils

As more *Homo habilis* fossils emerged throughout the 1970s and 1980s from sites across East and South Africa, scientists encountered an unexpected challenge: these specimens displayed considerable variation. Some were small and **gracile** like the original finds, while others, such as the KNM-ER-1470 skull from Lake Turkana (shown in Figure 12.3.2), exhibited larger brains, broader faces and bigger teeth.

This diversity has generated ongoing debates that continue today. Do all these fossils represent the same species, or should they be divided into multiple groups? Some researchers advocate recognizing at least two distinct species: *Homo habilis* and *Homo rudolfensis*. Others question whether these fossils are sufficiently "human" to belong in the genus *Homo* at all, suggesting they might be better classified as australopithecines.



Figure 12.3.2: Cast of the Homo habilis cranium KNM-ER-1470 from Kenya. This cranium has a wide, flat face, larger brain size, and larger teeth than other Homo habilis fossils, leading some scientists to give it a separate species name, Homo rudolfensis. Credit: Homo rudolfensis Cranium KNM-ER 1470 by ©BoneClones is used by permission and available here under a CC BY-NC 4.0 License.



Figure 12.3.3: Cast of the Homo habilis cranium KNM-ER 1813 discovered by Kamoya Kimeu in Koobi Fora, Kenya in 1973. Credit: Homo habilis cranium KNM-ER 1813 by ©BoneClones is used by permission and available here under a CC BY-NC 4.0 License

Recent discoveries have only intensified this complexity. In 2015, scientists announced the discovery of a 2.8-million-year-old jaw from Ethiopia that might represent the earliest known member of our genus, pushing the origins of *Homo* even further back in time (Villmoare et al. 2015). Given the incomplete and fragmentary fossil record from this period, such classification controversies are perhaps inevitable. Since scholarly consensus has not yet emerged regarding the classification of early *Homo*, this chapter uses the single (inclusive) *Homo habilis* species designation.



Figure 12.3.4: Map showing major sites where *Homo habilis* fossils have been found. Ledi-Geraru is located in Ethiopia, Koobi Fora and Lake Turkana Basin are located in Kenya, the Olduvai Gorge is located in Tanzania, and Tuang, Malapa, Rising Star and Sterkfontein are located in South Africa. Credit: Homo habilis site map (Figure 10.4) original to Explorations: An Open Invitation to Biological Anthropology by Chelsea Barron at GeoPlace, California State University, Chico is under a CC BY-NC 4.0 License.

Why *Homo habilis* Matters

Whether *Homo habilis* represents one species or several, and regardless of exactly where it fits on our family tree, it's appearance in the human fossil record represents an important evolutionary turning point. This species marked the beginning of a uniquely human relationship with technology. For the first time in hominin evolution, survival depended not just on biological adaptations but on the ability to modify the environment through toolmaking. The pattern established by *Homo habilis,* using intelligence and tools to exploit new ecological niches and transform their interaction with the environment, was about to go next level with the appearance of *Homo erectus*.

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12.4: Homo erectus

A New Kind of Human: Our First Global Ancestors

Two million years ago, a new type of early human appeared on the African landscape. Meet *Homo erectus*, literally "upright man," our first truly global ancestors who dared to leave Africa and explore the wider world. Unlike earlier hominins that were still quite small in stature, these hominins moved with a much more human stride. Their long, powerful legs carried them efficiently across vast distances, and their upright posture was fully committed to life on the ground. At first glance, you might think they look surprisingly familiar, but if you look closer, you'd notice some striking differences from modern humans. Their skulls were long and low rather than rounded like ours and they had thick cranial bones with pronounced brow ridges. The back of their heads featured a horizontal ridge called an **occipital torus** that gave them a squared-off appearance, and some had a slight thickening along the top of their skull called a **sagittal keel**. Instead of a pointed chin like ours, their **mandible** (lower jaw) receded backward, and their face showed less **prognathism** (forward projection) than earlier hominins.

Perhaps most importantly, their brains were much larger than their predecessors—averaging close to 1000 cubic centimeters compared to *Homo habilis*' 650-750 cc. This represented a major leap in cognitive capacity, though they still had a way to go before reaching our modern brain size of about 1,400 cc.

The story of *Homo erectus* becomes even more intriguing when we consider the remarkable diversity found in their fossil record. Scientists continue to debate whether the fossils from Africa, Asia, and the Republic of Georgia represent one species or several. The Asian specimens tend to have thicker skulls and more pronounced brow ridges, while African fossils show different characteristics. Some researchers argue these differences are significant enough to split African *Homo erectus* into a separate species called *Homo ergaster*. For our purposes, we'll follow the convention of using *Homo erectus* to describe this diverse group of early human ancestors who despite their cranial differences, shared so many fundamental similarities.



Figure $12.4.1a-c$: a) *Homo erectus* (*ergaster*) skull from Africa; b) *Homo erectus* skull Dmanisi, Georgia; c) *Homo erectus* skull from Asia. All skull reconstructions by ©BoneClones used by permission and available here under a CC BY-NC 4.0 License.

Bodies Built for Adventure

One of the most remarkable aspects of *Homo erectus* was their body plan which represented a dramatic departure from earlier hominins. While *Homo habilis* and the australopithecines were small-statured with long arms and short legs, still showing adaptations to an arboreal lifestyle, *Homo erectus* was built for life on the ground and for long-distance travel.

Their legs were 54% longer than Lucy's, and fossilized footprints discovered on an ancient lakeshore in Africa reveal they had

developed a fully modern human arch, giving them more spring in their step (DeSilva 2021). These adaptations represented a fundamental shift in lifestyle. Studies have linked several characteristics of *Homo erectus* to long-distance running in the increasingly open savanna environment during this phase of the Pleistocene (Bramble and Lieberman 2004).

This athletic build came with some interesting biological trade-offs. Many experts believe that around this time, hominins lost much of their body hair, became particularly efficient at sweating, and developed darker-pigmented skin—all traits that would support the active lifestyle of such large-bodied early humans living under the African sun (Jablonski 2010).

Much of what we know about *Homo erectus* body build comes from one famous discovery: the Nariokotome boy, whose nearly complete skeleton was found in Kenya. Initially, researchers estimated he would have grown to over six feet tall, but recent reassessments suggest a more modest 5 feet 4 inches. This revision reflects a broader pattern emerging from new discoveries—*Homo erectus* fossils show more variation in body size than previously thought, possibly representing adaptations to different local environments, just as humans today show reduced body size in nutritionally poor environments (Anton and Snodgrass 2012).



Figure 12.4.2: KNM-WT 15000 Turkana Boy Skeleton by Smithsonian [exhibit: Human Evolution Evidence, Human Fossils, Fossils, KNM-WT 15000] is copyrighted and used for educational and non-commercial purposes as outlined by the Smithsonian.

Paleoanthropologist Profile

Fossil Hunter: Kamoya Kimeu

Kamoya Kimeu (1938–2022) is arguably the most prolific fossil hunter in the history of paleoanthropology (Figure 10.8). In addition to his many decades of work as a field excavator and project supervisor in East Africa, he also trained field workers and scholars and has served as curator for prehistoric sites for the National Museum of Kenya.



Figure 12.4.3: Kamoya Kimeu (1938-2022). Credit: Photograph of Kamoya Kimeu by ©Dr. Mark Teaford is used by permission.

Kamoya Kimeu was born in 1938 in rural southeastern Kenya. Despite a formal education that did not go past the sixth grade, he had an aptitude for languages and familiarity with the plants and animals in the East African bush that led him to a job in Tanzania as a field excavator for Louis and Mary Leakey in 1960. In the years that followed, Kimeu found dozens of major hominin fossils. These included a *Paranthropus boisei* mandible at Olduvai Gorge, *Homo habilis* specimen KNM-ER-1813 from the Turkana Basin (shown in Figure 10.5), and a key early modern *Homo sapiens* fossil from the Omo Valley, Ethiopia. Kimeu's most famous fossil discovery was the skeleton of a young *Homo erectus* by the Nariokotome river bed in 1984. This finding was highly significant because it was a nearly complete early hominin skeleton and provided insight into child development within this species. In recognition of his work, Kimeu was awarded the National Geographic Society La Gorce Medal by U.S. President Ronald Reagan in 1985.

Traditionally, there has been a divide between African field workers and foreign research scientists, who would typically conduct seasonal field work in Africa, then travel back to their home institutions to publish their findings. Although Kimeu received widespread acclaim for the Nariokotome discovery, as well as a personal acknowledgement in the publication of the find in the journal *Nature*, he was not credited as an author. More recently, Kimeu's intellectual contributions to the field of paleoanthropology have been recognized. In 2021, he received an honorary doctorate degree from Case Western Reserve University in Ohio. Kimeu's most lasting legacy may be his mentorship of countless field workers and students. Today, there are a small but growing number of Black African paleoanthropologists taking on principal roles in the science of human origins.

The Early Human Globetrotter

Here's where the *Homo erectus* story becomes truly extraordinary. Unlike all previous hominins who remained in Africa, *Homo erectus* became the first species in our lineage to venture beyond the African continent. By 2.1 million years ago, they had pushed clear across the Asian continent, and by 1.5 million years ago, they had made it to Southeast Asia, reaching the island of Java during a period when lower sea levels made the journey possible (DeSilva 2021).

What drove them beyond their African homeland? Anthropologists suggest that the answer lies in their biology, culture, and changing world. Their larger brains and bodies required more calories, and their diet had shifted to include significantly more meat. Since they were eating higher on the food chain, they needed larger territories to find sufficient game. Their longer, more powerful legs made it possible to walk and run the distances necessary to follow migrating herds.

Cultural (behavioral) developments played a crucial role too. *Homo erectus* possessed better stone tools and were the first to harness fire. These technological advances gave them greater flexibility in adapting to different environments.

The timing of these cultural advancements wasn't random. Major mid-Pleistocene climate shifts altered animal and plant

communities across Africa and Eurasia. As *Homo erectus* increasingly relied on hunting, the migration patterns of their prey led them across increasingly long distances. These migrations likely happened in pulses, corresponding with climate fluctuations and animal migration patterns. As paleoanthropologist Jeremy DeSilva notes, "*Homo erectus* moved in and out of Africa and gradually began exploring territories never before inhabited by an upright walking hominin" (2021:138-139).

The fossil evidence tells this story across multiple continents. In Dmanisi, Georgia, we find *Homo erectus* skeletons that still exhibit the long legs and body proportions of modern humans. The famous "Peking Man" fossils from near Beijing, dated to about 400,000-700,000 years ago, represent some of the most famous human fossils in the world and demonstrate how successfully these early humans adapted to northern Chinese environments.

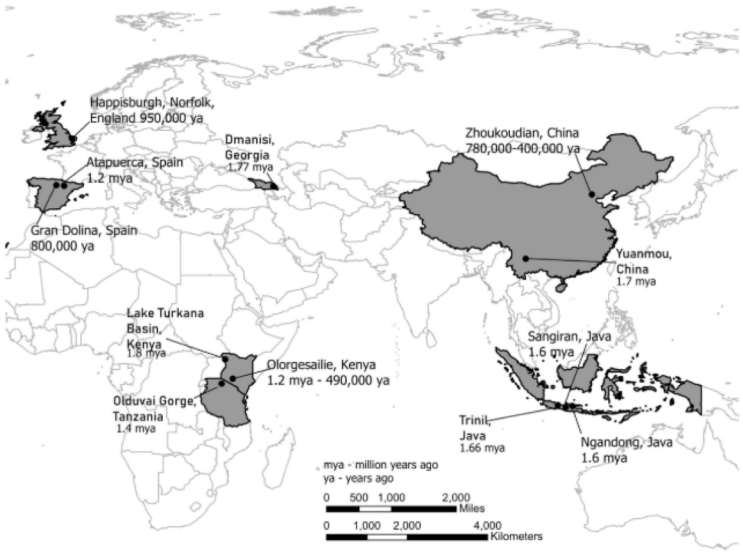


Figure 12.4.4: Map showing the locations of Homo erectus fossils around Africa and Eurasia. Credit: Homo erectus site map original to Explorations: An Open Invitation to Biological Anthropology by Chelsea Barron at GeoPlace, California State University, Chico is under a CC BY-NC 4.0 License. [Image Description]

The Acheulean Toolkit

The technological innovations of *Homo erectus* represent another major leap in human evolutionary development. While early African sites associated with *Homo erectus* still contain simple Oldowan-style choppers and flakes, around 1.5 million years ago, some populations began creating something entirely new: the **Acheulean** tool industry.

Acheulean toolmakers carefully shaped both sides of their implements using a technique called bifacial flaking, which required significantly more planning and skill than anything seen before. The toolmaker needed to understand principles of symmetry and maintain a mental template of the finished product throughout the manufacturing process (Putt 2017; Stout 2016).

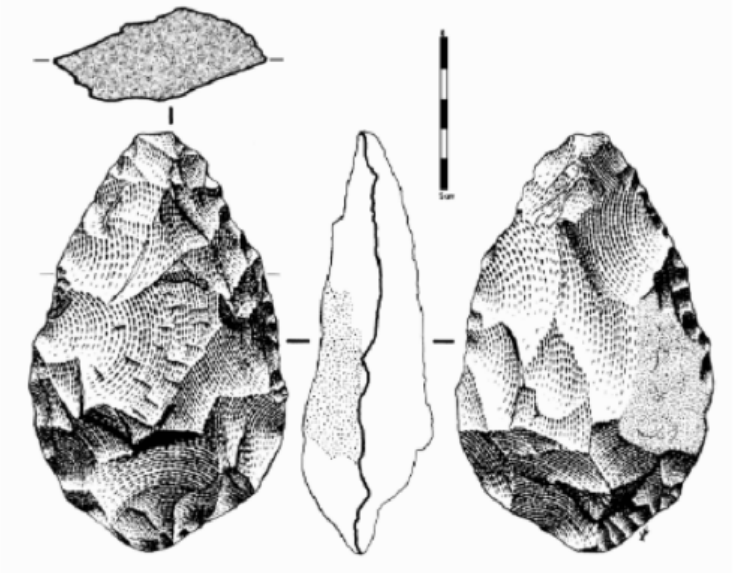


Figure 12.4.5: Drawing of an Acheulean handaxe. This specimen is from Spain. When drawing a stone tool, artists typically show front and back faces, as well as top and side profiles. Credit: Hand axe spanish by José-Manuel Benito (user: Locutus Borg) has been designated to the public domain (CC0).

The signature tool of this industry was the handaxe, a teardrop-shaped implement that was thicker at the base and came to a rounded point at the tip. What's remarkable about these handaxes isn't just their sophisticated design, but their incredible uniformity. Despite being manufactured by different individuals across vast distances and time periods, Acheulean handaxes show remarkable consistency in shape and proportions and remained virtually unchanged for over a million years.



Figure 12.4.6:Bifaced Acheulean handaxe. Credit: Muséum de Toulouse, CC BY-SA 4 via Wikimedia Commons.

The sophistication of Acheulean technology extends beyond the tools themselves. Analysis reveals that toolmakers often traveled considerable distances to seek out high-quality raw materials, sometimes even removing large slabs of rock to access the most desirable stone. Such complex activities would require advanced planning and communication with other group members. However, not all *Homo erectus* populations showed this level of selectivity. Some sites show evidence of using whatever materials were immediately available (Shipton et al. 2018).

Interestingly, this sophisticated Acheulean technology was largely absent from East Asian *Homo erectus* sites, where simpler Oldowan style tools continued to dominate. This geographic pattern has puzzled researchers and led to several competing explanations. Perhaps Asian populations relied more heavily on perishable materials such as bamboo for toolmaking, or maybe the first migrants left Africa before Acheulean technology fully developed there. The recent discovery of 2.1-million-year-old tools

in China lends support to this latter explanation.

The Hunt for Calories: Diet, Subsistence, and Cooking

Understanding what *Homo erectus* ate provides crucial insights into their biology and behavior. Multiple lines of evidence including stone tools, animal bones from archaeological sites, and analysis of hominin teeth and bones, paint a picture of a species that had significantly increased its consumption of animal protein compared to previous hominins.

This dietary shift makes perfect biological sense. Larger brains and bodies require more calories, and the brain is particularly energy-hungry, demanding more than 20% of our total caloric intake. When biologists study the evolution of intelligence in any animal species, they frame it as a cost-benefit analysis: for large brains to evolve, there must be compelling benefits and reliable ways to generate enough energy to fuel them.

The solution that *Homo erectus* appears to have adopted follows what researchers call the "expensive tissue hypothesis," formulated by Leslie Aiello and Peter Wheeler (1995). According to this model, a smaller gut would allow for a larger brain without requiring a corresponding increase in the organism's metabolic rate. More meat in the diet—being more calorically dense than plant foods—could fuel both the larger brain and body size we see in the genus *Homo*. Some researchers also believe that body fat percentages increased in hominins around this time, particularly in females, providing better buffering against environmental disruptions like food shortages (Anton and Snodgrass 2012).

Archaeological evidence supports this shift toward increased meat consumption. Sites like Olorgesailie in Kenya show numerous associations between Acheulean tools and butchered remains of large animals, suggesting that *Homo erectus* had moved beyond simple scavenging to active hunting of substantial prey.



Figure 12.4.7: Excavations at the site of Olorgesailie, Kenya. Dated from between 1.2 million years ago and 490,000 years ago, Olorgesailie has some of the most abundant and well-preserved evidence of Homo erectus activity in the world. Fossils of large mammals, such as elephants, along with thousands of Acheulean tools, have been uncovered over the decades. Credit: Elephant Butchery Site Olorgesailie, Kenya by Smithsonian [exhibit: Human Evolution Research, East African Research Projects, Olorgesailie, Kenya] is copyrighted and used for educational and non-commercial purposes as outlined by the Smithsonian.

However, *Homo erectus* certainly didn't survive on meat alone. Analysis of tooth surfaces and microscopic wear patterns reveals they ate a variety of foods, including hard, brittle plant materials (Unger and Scott 2009). This dietary diversity made sense in their changing world, where grasslands were expanding and new food sources were becoming available.

In the unstable environment of the early Pleistocene, with its fluctuating climate and changing ecosystems, dietary versatility would have been a definite survival advantage. This flexibility, combined with their technological innovations and physical adaptations, helps explain how *Homo erectus* became the first hominin species to successfully expand into such diverse environments across Africa, Asia, and beyond.

One key characteristic of the genus *Homo* is smaller teeth compared to *Australopithecus*. Why would teeth get smaller? In

addition to new types of foods, changes in how food was prepared and consumed likely led to a decrease in tooth and jaw size. As stone tools became increasingly important, hominins began to cut up, tenderize, and process meat and plants, which means that they did not have to put as much pressure on their teeth and jaws.

In fact, anthropologist Richard Wrangham (2009) asserts that cooking played a crucial role in human evolution. Cooking provides a head start in the digestive process because of how heat begins to break down food before it even enters the body, and it can help the body extract more nutrients out of meat and plant foods such as starchy tubers.



Figure 12.4.8: Fire. Image by Alexa from Pixabay

Clearly, cooking requires fire, and the earliest use of fire is an intriguing area of study in human evolution. Fire occurs naturally from lightning strikes, and early hominins must initially have feared wildfires like other animals. At some point, they learned to control fire and use it to their advantage. Documenting the earliest evidence of fire has been a contentious issue in archaeology because of the difficulty in distinguishing between human-controlled fire and natural burning at hominin sites. Burned areas and ash deposits must have direct associations with human activity to make a case for deliberate fire use. Unfortunately, such evidence is rare at ancient hominin sites, which have been profoundly altered by humans, animals, and geological forces over millions of years. Recently, newer methods—including microscopic analysis of burned rock and bone—have revealed clear evidence of fire use at Koobi Fora, Kenya, dating to 1.5 million years ago (Hlubik et al. 2017).

A Legacy of Success

The story of *Homo erectus* represents a pivotal chapter in human evolution---the moment when our ancestors first became truly global. Their combination of larger brains, more energy efficient bodies, sophisticated technology, and dietary flexibility created a successful recipe for survival that lasted for nearly two million years across multiple continents.

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12.5: Putting It All Together- How Diet, Tools and Movement Made Us Human

Homo omnivorous

Walk into any gym or scroll through social media today and you'll encounter influencers promoting "carnivore diets" or "ancestral eating" plans that claim humans evolved as primarily meat-eaters. They'll tell you that our ancestors thrived on little else but animal protein, and that's what we should return to for optimal health. But here's the problem with that narrative: it's simply not supported by the scientific evidence (Wong 2024). The real story of human evolution is far more interesting and complex than these modern diet influencers claim. It's not just about what we ate, but how we moved to get our food and what tools we made to process it that shaped us into the humans we are today.



Figure 12.5.1: Steak on a grill. Image by Chil Vera from Pixabay

For nearly half of our evolutionary lineage's history, there's no material evidence of meat-eating at all. Our earliest ancestors ate much like other primates do today: fruits, nuts, seeds, roots, flowers, leaves, insects, and the occasional small mammal. This plant-heavy, but varied diet sustained our ancestors for millions of years as they developed one of the most distinctive human traits: walking upright. As we've learned, bipedalism fundamentally reshaped the human body from head to foot. But walking was just the beginning of our movement story.

The Revolutionary Shift: Tools, Brains, and Meat

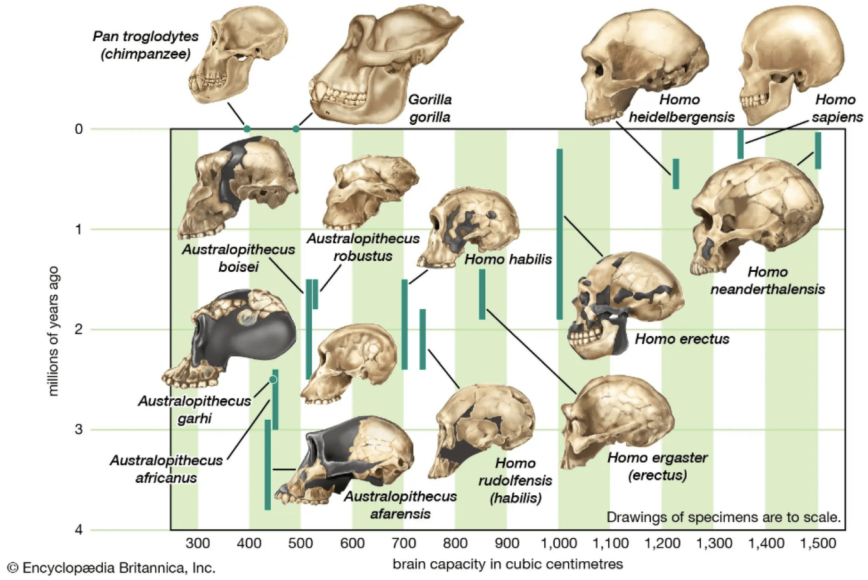


Figure 12.5.2: Brain size comparisons in non-human primate and fossil hominins. Credit: Encyclopedia Britannica, Inc. Used in compliance with Terms of Use Agreement.

Between 2.6 million and 200,000 years ago, the human brain more than doubled in size. This dramatic growth coincides almost perfectly with two major developments: the creation of stone tool traditions and the shift toward persistent **carnivory**. The simple Oldowan tools of *Homo habilis* came first, followed by the more sophisticated Acheulean hand axes made by *Homo erectus*, and eventually, by the more varied and sophisticated tool kits of later genus *Homo* hominins. As our ancestors began creating increasingly sophisticated tools, evolving into what archaeologist Dietrich Stout calls *Homo artifex*, humans known for their craftsmanship and technical skill, this process began rewiring the brain itself (Stout 2016).

Experimental archaeology and modern neuroscience have revealed just how profound the connection between toolmaking and brain development really was during the beginnings of the Stone Age. When Stout and his team taught students to recreate ancient stone tools while scanning their brains, the results were striking. Simple Oldowan tools activated basic visual and spatial areas, but the bi-faced, more refined Acheulean hand axes, requiring careful planning and precise control, lit up the prefrontal cortex, particularly regions involved in cognitive control and decision-making (Putt 2017).



Figure 12.5.3: The stone flakes are flying, but what brain regions are firing? Credit: Shelby S. Putt, CC BY-ND

They also found that learning to make these tools literally rewired students' brains. The more hours they practiced (some

spent over 300 hours mastering these techniques), the stronger the neural connections became between brain regions. When researchers compared human and chimpanzee brains, they found that humans have much more extensive toolmaking circuits, especially in areas that recent studies have found also process language, music, and complex movements (Stout 2016).

Built to Run

But using tools to process meat and extract marrow from various mammals is only part of the story. These taller, leaner, and more active hominins also developed an extraordinary hunting technique: persistence hunting through endurance running (Pontzer 2019). While other predators have to rely on short bursts of speed to catch prey, *Homo erectus* took a different approach. They chased animals to exhaustion in the heat of the day using their remarkable capacity for endurance running. Their success was less about being the fastest and more about being the most persistent.

Daniel Lieberman, known as the "barefoot professor" for walking shoeless around campus and for his research on natural human movement patterns, points out that we're anatomically designed to be exceptional distance runners and walkers. The arches in our feet store energy like springs with each step. Our long tendons, including the Achilles tendon, also act like springs, making our movement efficient over long distances. Our short toes, unlike those of our primate relatives, are perfectly designed for running. Lieberman notes that our feet contain numerous sensory nerves that provide detailed feedback to our brain and central nervous system, all working together in a sophisticated energy feedback system (Barbu 2022).



Figure 12.5.4: Barefoot in the rain. Image by Ollebolle123 from Pixabay

This combination of tool-making and endurance hunting marked the beginning of consistent carnivory, as evidenced by bone assemblages at Homo erectus sites (DeSilva 2021). The addition of nutrient-dense meat helped fuel the dramatic brain growth that would become a hallmark of our lineage. But here's the key point that modern carnivore diet advocates miss: meat didn't *replace* the existing diverse diet. Instead, it was *added* to it, creating an even more varied omnivorous pattern (Wong 2024).

The Triple Advantage: Movement, Diet, and Cognition

What truly defines the human lineage isn't just one evolutionary development, but the *broadening* of our capabilities across three key areas: our diet, our movement, and our cognitive abilities. This gave our species an incredible competitive edge: the ability to "go anywhere," "eat anything," and "figure out how to get it." Being an omnivore played a key role in this. When we think about other successful omnivores in nature such as rats, crows, and many primates, it's no coincidence that they tend to be remarkably intelligent. Omnivores must constantly track complex information such as where different foods are located, when they're available seasonally, which ones are safe to eat, and how to obtain them. Similarly, our movement capabilities had to be equally flexible. Sometimes we needed to walk long distances to new territories, sometimes we needed to run down prey, and sometimes we needed the fine motor control to make and use tools (Pontzer 2019).

Anatomy Reflects Our Triple Heritage

Just as our movement anatomy is specialized for endurance, our digestive anatomy reflects our omnivorous heritage, and our brain anatomy shows the deep connections between toolmaking, language, and complex reasoning. Our teeth are designed for both cutting and grinding, unlike the specialized dentition of true carnivores or herbivores. Our digestive system, complete with its complex microbiome, evolved to break down and extract nutrients from a wide variety of food sources. Our brains developed sophisticated circuits that could handle the demands of planning tool construction, tracking seasonal food sources, coordinating persistence hunts, and eventually, complex communication. As our ancestors spread across the globe, they encountered vastly different climates, terrains, and food sources. The ability to adapt their diet and their movement patterns to whatever local conditions demanded laid the foundation for our modern brains, bodies, and guts.

The Modern Disconnect

Lieberman's research highlights just how dramatically our modern lifestyle has diverged from our evolutionary heritage. We've created a world where many people barely walk their recommended 10,000 steps per day, let alone engage in the kind of varied, natural movement our bodies evolved to perform. Similarly, many of us have moved away from the dietary diversity that characterized our evolutionary success, instead following restrictive eating patterns our ancestors never would have survived on. And most of us have largely been separated from the hands-on toolmaking and complex skill development that helped wire our brains for sophisticated thinking.

Now, our feet, designed to provide detailed sensory feedback to our nervous system, spend most of their time trapped in cushioned shoes. Our bodies, built for endurance and varied movement, spend hours sitting in chairs. Our digestive systems, evolved to handle seasonal variety, often process the same few foods day after day. Our hands and brains, evolved for complex toolmaking and skill development, spend most of their time tapping on screens rather than creating physical objects.



Figure 12.5.5: Man working on computer with headphones. Image by Samuel Bourke on Unsplash

The Lesson for Today

Understanding our true evolutionary heritage offers valuable perspective on nutrition, fitness, and learning. Rather than seeking the "one perfect diet," "one perfect workout," or "one perfect learning method," we might be better served by embracing the flexibility that made us human in the first place. Our evolutionary story suggests that adaptability and variety in what we eat, how we move, and how we engage our minds have been our species' greatest strengths.

The experiments with recreating early stone tools also reveal something profound about how we learn. The patience and persistence required to master complex skills, whether it's crafting a stone tool, developing confidence with statistics, or learning a new language, are deeply rooted evolutionary traits that helped our ancestors survive. Every time you struggle through a

difficult assignment, persist through a challenging workout, or experiment with new foods, you're exercising the same cognitive and physical capabilities that made us human. When you feel frustrated with a difficult class or want to give up on learning something new, rest assured that your brain has literally been built for this challenge. Those neural pathways that connect planning, persistence, and skill development were forged over millions of years of our ancestors patiently working stone, tracking game across vast distances, and figuring out which foods were safe to eat in new environments.

As the saying goes, "variety is the spice of life." In the case of human evolution, variety in diet, movement, and cognitive challenges wasn't just the spice, it was the key ingredient that enabled our species' unprecedented global success. So the next time someone claims that humans evolved to eat only one type of food or that there's only one way to exercise or learn, remember: we are *Homo omnivorous*. Our evolutionary success story is written in the remarkable diversity of what we learned to eat, how we learned to move to get it, and what we learned to make to process it.

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12.6: Fossil Evidence

Fossil Evidence for *Homo habilis*

Figure 12.6.1: Key Homo habilis fossil locations and the corresponding fossils and dates. Credit: Homo habilis table (Figure 10.6) original to Explorations: An Open Invitation to Biological Anthropology by Bonnie Yoshida-Levine is under a CC BY-NC 4.0 License.

Location of Fossils	Dates	Description
Ledi-Gararu, Ethiopia	2.8 mya	Partial lower jaw with evidence of both *Australopithecus* and *Homo* traits; tentatively considered oldest Early *Homo* fossil evidence.
Olduvai Gorge, Tanzania	1.7 mya to 1.8 mya	Several different specimens classified as Homo habilis, including the type specimen found by Leakey, a relatively complete foot, and a skull with a cranial capacity of about 600 cc.
Koobi Fora, Lake Turkana Basin, Kenya	1.9 mya	Several different specimens classified as Homo habilis, including the type specimen found by Leakey, a relatively complete foot, and a skull with a cranial capacity of about 600 cc.
Sterkfontein and other possible South African cave sites	about 1.7 mya	South African caves have yielded fragmentary remains identified as *Homo habilis*, but secure dates and specifics about the fossils are lacking.

Fossil Evidence for *Homo erectus*

Figure 12.6.2: Regional comparisons of Homo erectus fossils. Credit: Regional comparisons of Homo erectus fossils (Figure 10.12) original to Explorations: An Open Invitation to Biological Anthropology is under a CC BY-NC 4.0 License.

Region	Sites	Dates	Significance of Fossils
East Africa	East and West Lake Turkana, Kenya; Olduvai Gorge, Tanzania	1.8 to 1.4 mya	Earliest evidence of *H. erectus*; significant variation in skull and facial features.
South Africa	Drimolen Cave, South Africa	2 mya	Recent find of a 2–3 year old child would be oldest *H. erectus* anywhere to date.
Western Eurasia	Dmanisi, Republic of Georgia	1.75 mya	Smaller brains and bodies than *H. erectus* from other regions.
Western Europe	Atapuerca, Spain (Sima del Elefante and Gran Dolina caves)	1.2 mya–400,000 ya	Partial jaw from Atapuerca is oldest evidence of *H. erectus* in Western Europe. Fossils from Gran Dolina (dated to about 800,000 years) sometimes referred to as *H. antecessor*.
Indonesia	Ngandong, Java; Sangiran, Java	1.6 mya	Early dispersal of *H. erectus* to East Asia; Asian *H. erectus* features.
China	Zhoukoudian, China; Loess Plateau (Lantian)	780,000–400,000 ya; 2.1 mya	Large sample of *H. erectus* fossils and artifacts. Recent evidence of stone tools from Loess Plateau suggests great antiquity of *Homo* in East Asia.

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12.7: Key Terms

Acheulean tool industry - Tool industry characterized by teardrop-shaped stone handaxes flaked on both sides.

Carnivory – consuming the meat of animals

Cognitive – anything related to thinking, learning, and understanding

Gracile – exhibiting more slender features

Mandible – the lower jawbone

Mosaic evolution - Different characteristics evolve at different rates and appear at different stages.

Occipital torus – A ridge on the occipital bone in the back of the skull.

Oldowan tool industry - Earliest stone-tool industry consisting of simple flakes and choppers.

Pleistocene - Geological epoch dating from 2.6 million years ago to about 11,000 years ago.

Primatological - anything related to primatology, the study of primates

Prognathic/Prognathism - Condition where the lower face and jaw protrude forward from a vertical plane.

Sagittal keel - A thickened area along the top of the skull.

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13: BECOMING HUMAN

13.1: Surviving the Middle Pleistocene

13.2: Archaic Homo Sapiens

13.2.1: The Neanderthals

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13.5: Key Terms

13.6: References and Attributions

Learning Objectives

- Identify the main groupings of Archaic *Homo sapiens*, such as Neanderthals.
- Explain how shifting environmental conditions required flexibility of adaptations, both anatomically and behaviorally.
- Describe the unique anatomical and cultural characteristics of Archaic *Homo sapiens,* including Neanderthals, in contrast to other hominins.
- Evaluate how Middle Pleistocene hominin fossils fit into evolutionary trends including cranial capacity (brain size) development, cultural innovations, and migration patterns.
- Consider how anatomically modern humans were different from other hominins and how their cultural and technological innovations have and continue to shape the planet

Did You Know?

Does Paleogenomics Hold the Key to Personalized Medicine?

It seems like almost every month we hear about a new study that expands our understanding of how Neanderthal DNA affects modern human health and physiology. Recently, researchers have found that Neanderthal DNA can influence everything from our skin and hair color, how prone we are to certain skin cancers or metabolic diseases such as diabetes, and how easily our blood clots. Carriers of Neanderthal DNA may have a propensity for addictive behaviors, autism, depression, and be vulnerable to allergies and immune disorders such as lupus and Crohn's disease (Cassanova and Feltus 2025:44; Marris 2016; Lee 2015:184).



Figure 13.1:Homo sapiens (left) and Neanderthal (right) skulls. Image by hairymuseummatt (original photo), DrMikeBaxter (derivative work), CC BY-SA 2.0, via Wikimedia Commons

One especially intriguing study concerns the possible link between Neanderthal ancestry and autism. The lead researchers on the study note that while the medical community has traditionally focused on the deficits and challenges that people with autism experience, "the autism spectrum is also associated with traits that may have been adaptive during more recent human brain evolution—enhanced visuospatial processing, high intelligence, exceptional memory and creativity, among others." (Cassanova and Feltus 2025:47). How and to what degree Neanderthal DNA has and may continue to influence or alter gene expression in brain development is an exciting frontier in the emerging field of paleogenomics. The more we uncover the parts of our genetic ancestry we share with our Neanderthal and Denisovan cousins, the more we understand that their story is central to our story, and may lead us to a variety of potential therapeutic applications within the burgeoning field of personalized medicine.

Why the "Cave Man" Stigma?[i]

What do you think of when you hear the word "caveman"? Perhaps you imagine a character from a film such as *The Croods*, *Tarzan*, and *Encino Man* or from the cartoon *The Flintstones*. Maybe you picture the tennis-playing, therapy-going hairy Neanderthals from Geico Insurance commercials like the ones featured below.

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

Our Nostalgic Memories. (2022, October 26) Geico Caveman Commercials [Video]. YouTube https://youtu.be/-Y7HDXBVbfc?si=uPSliKOkrXtNcuDs

Or perhaps you imagine characters from *The Far Side* or *B.C.* comics. Whichever version you envision, the character in your mind is likely stooped over with a heavy brow, tangled long locks and other body hair, and clothed in animal skins, if anything. They might be holding a club with a confused look on their face, standing at the entrance to a cave or dragging an animal carcass to a fire for their next meal. You might have even signed up to take this course because of what you knew—or expected to learn—about "cavemen." As archaeologist and scientific historian, Stephen Nash, points out,

> "Neanderthals have been the brunt of cruel jokes and the target of scientific and popular discrimination since the discovery of a Neanderthal skull cap in 1856 at Germany's Feldhofer cave. It hasn't helped that the first reasonably complete skeleton of a Neanderthal, found at La Chapelle aux Saints in southern France in 1908, was a toothless old man who suffered terribly from arthritis and other ailments. When first reconstructed and depicted by paleontologist Marcellin Boule, the skeleton was drawn stooped over and as if he was shuffling. The old marketing adage "you never get a second chance to make a good first impression" appears to ring true: Boule's reconstruction remains remarkably influential even today" (Nash 2017).

These images have long been the stigma and expectation about our ancestors at the transition to modern *Homo sapiens*. Tracing back to works as early as Carl Linnaeus, scientists once propagated and advanced this imagery, creating a clear picture in the minds of early scholars that informed the general public, even through today, that Archaic *Homo sapiens*, "cavemen," were somehow fundamentally different and much less intelligent than we are now. Unfortunately, this view is overly simplistic, misleading, and incorrect. Understanding what Archaic *Homo sapiens* were actually like requires a much more complex and nuanced picture, one that comes into sharper focus as continuing research uncovers more about the lives of our not-too-distant (and not-too-different) ancestors.



Figure 13.2:Mural of a Neanderthal family by Charles Robert Knight, Public domain, via Wikimedia Commons

These early characterizations of Archaic *Homo sapiens* were formed from limited fossil evidence in a time when **ethnocentric** perspectives were more widely accepted and entrenched in both society and science. Today, scientists are working from a more complete fossil record from three continents (Africa, Asia, and Europe), and genetic evidence informs their analyses and conclusions. The existence of Archaic *Homo sapiens* marks an exciting point in our lineage—a point at which many modern traits had emerged and key refinements were on the horizon. Anatomically, humans today are not that much different from Archaic *Homo sapiens*.

The Final Chapters in Our Evolutionary Story

This chapter will examine how the environment with which Archaic *Homo sapiens* had to contend shaped their biological and cultural evolution. We'll highlight the key anatomical traits that define this group of fossils, focusing on the most well-known of them, including Neanderthals. We'll also consider how cultural innovations aided their adaptation to the changing environment, as well as their geographic distribution and regional variations. Additionally, we'll discuss exciting new research that suggests even greater nuance and complexity during this time period. And finally, we'll evaluate how the "human revolution" has led to our outsized impact on the planet and what this means for the future of humanity and all species on Earth.

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[i] This section was adapted from Wolcott Paske, Amanda, and AnnMarie Beasley Cisneros. (2023). 11.1: Breaking the Stigma of the "Caveman. In *Explorations: An Open Invitation to Biological Anthropology, Second edition,* edited by Beth Shook, Katie Nelson,

Kelsie Aguilera, and Lara Braff. Open Educational Resource, licensed under CC BY-NC 4.0.

Thumbnail image: Diverse hands forming a circle around a globe. Canva design.

Answers

- 13.2.1: The Neanderthals
- 13.2.2: The Denisovans
- 13.2.3: Five Human Species You May Not Know About

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13.1: Surviving the Middle Pleistocene

A World in Flux

Like all living things today and in the past, our ancestors had to deal with and respond to changing climates, landscapes, and resources. The Middle Pleistocene (roughly 700,00 – 130,000 years ago) was marked by periods of fluctuation, not just the cold periods we associate with the “Ice Age.” Interglacials interrupted glaciations, reversing trends in sea levels, coastlines, temperature, precipitation, and aridity, as well as glacier size and location.

These periods are marked by increased rainfall and a higher temperature, which causes the ice built up in glaciers to melt. This leads to glacial retreat, which is the shrinking of glaciers and the movement of the glaciers back toward the poles, as we’ve been witnessing during our lifetime. During the interglacials , sea level rose, flooding previously dry land and severing connections between continents. Plant and animal communities shifted accordingly, often finding more temperate climates to the north and less arid and more humid climates in the tropics (Van Andel and Tzedakis 1996).

Our human ancestors couldn't escape these dramatic environmental changes, no matter where in the world they lived. As climate zones shifted, so did food sources. Animals that had been reliable sources of protein either migrated to follow their preferred climates or went extinct entirely. Plant foods that communities had depended on for generations suddenly became scarce or disappeared altogether.

Water sources presented another challenge. During glacial periods, when sea levels were lower, humans had access to more dry land but often faced limited freshwater resources. During interglacials, rising seas and increased rainfall meant more available freshwater but less land to live on. The land bridges that had allowed people to move between continents on foot would appear during glacial periods and vanish during interglacials sometimes leaving populations stranded.

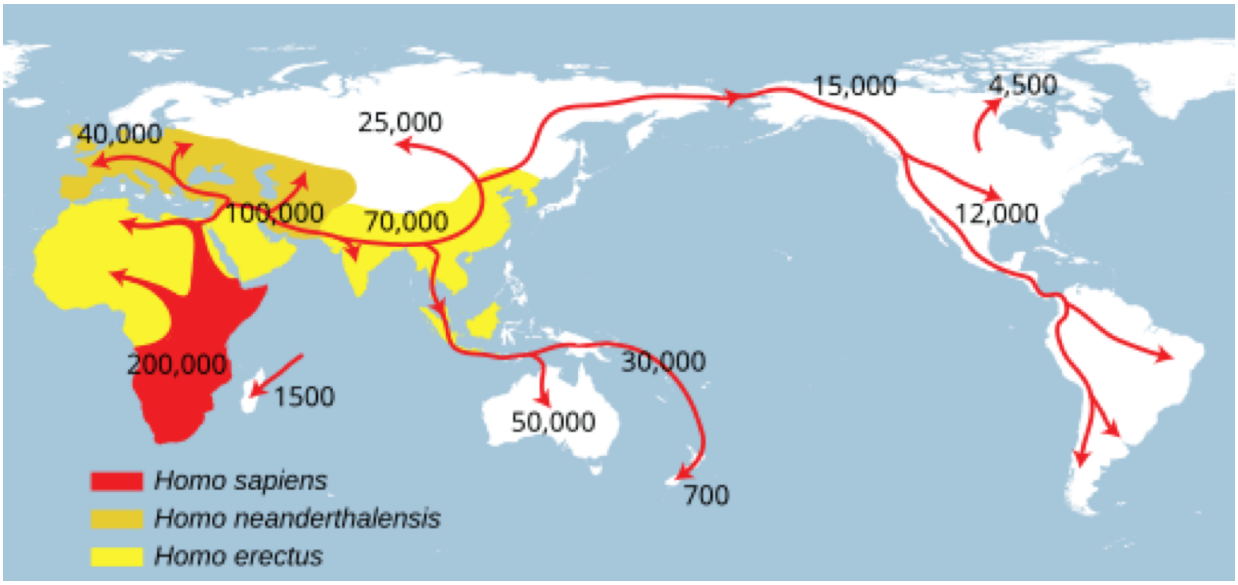


Figure 13.1.1: Spreading of hominins over the world; including Homo erectus, Homo neanderthalensis, and Homo sapiens. Image credit: NordNordWest, Public domain, via Wikimedia Commons

To understand just how dramatic these changes were, scientists have studied a region in southern Kenya called Olorgesailie. What they found there tells a remarkable story of environmental transformation. Over the course of the Middle Pleistocene, this single location was at different times a deep lake, a drought-stricken lakebed crisscrossed by the streams, and a vast grassland. Each transformation brought new challenges for the animals living there.

The Generalist Advantage

As the environment shifted, so did the animal communities. Some species couldn't adapt and went extinct, while others thrived in the new conditions. Scientists noticed a clear pattern emerging: animals with highly specialized traits—like zebras with teeth designed only for eating grass—were more likely to disappear. Meanwhile, their more adaptable relatives—zebras that could eat both grass and other vegetation—survived and flourished.



Figure 13.1.2: Zebras feeding with other grassland animals. Image credit: Swiftaurora, CC BY-SA 4.0, via Wikimedia Commons

This pattern of "generalists over specialists" would prove to be one of the most important survival strategies of the Middle Pleistocene, and it didn't just apply to zebras. Archaeological evidence suggests that *hominin* populations that were most adaptable—those that could adjust their diets, modify their tools, and change their survival strategies as needed—were the ones most likely to thrive during this period of constant change.

This adaptability became one of our greatest evolutionary advantages. Rather than specializing in exploiting one particular environment or food source, our ancestors developed the flexibility to survive in grasslands, forests, deserts, and coastal regions. They learned to hunt different animals, gather new types of plants, and create tools suitable for various environments.

The Middle Pleistocene was essentially a 570,000-year-long test of survival skills, and the humans who made it through this period passed on more than just their genes—they passed on the behavioral flexibility and innovative thinking that would eventually allow our species to spread across the entire globe.

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13.2: Archaic Homo Sapiens

Defining Characteristics

Archaic *Homo sapiens* share our species name but are distinguished by the term “Archaic” as a way of recognizing both the long period of time between their appearance and ours, as well as the way in which human traits have continued to evolve over time—making Archaic *Homo sapiens* look slightly different from us today, despite being considered the same species. Living throughout Africa, and the Middle East during the Middle Pleistocene, Archaic *Homo sapiens* are considered, in many ways, transitional between *Homo erectus* and modern *Homo sapiens*.

Archaic *Homo sapiens* share the defining trait of an increased brain size of at least 1,100 cc and averaging 1,200 cc, although there are significant regional and temporal (time) variations. Because of these variations, scientists disagree on whether these fossils represent a single, variable species or multiple, closely related species.

An active area of scholarship in the discipline involves reconciling the diversity of species from this time period and establishing the **phylogenetic** relationships between them. The term “Archaic *Homo sapiens”* can mean different things to different scholars within the discipline.

Since there is no consensus on the classification of this fossil material, this chapter will rely on the widely used naming conventions that refer to many fossils from this time period as Archaic *Homo sapiens* and will consider them as a unit, with the exception of a particularly unique population living in Europe and West Asia known as the Neanderthals, which will be examined in the next section.

When comparing *Homo erectus*, Archaic *Homo sapiens,* and anatomically modern *Homo sapiens*, one can see that Archaic *Homo sapiens* are intermediate in their physical form. For some features, this follows the trends first seen in *Homo erectus* with other features having early, less developed forms of traits seen in modern *Homo sapiens*. For example, Archaic *Homo sapiens* trended toward less angular and higher skulls than *Homo erectus.* However, the archaic skulls were not as short and globular and had less developed foreheads compared to anatomically modern *Homo sapiens.* Archaic *Homo sapiens* had smaller brow ridges and a less-projecting face than *Homo erectus* and slightly smaller teeth, although incisors and canines were often about as large as those of *Homo erectus*.



Figure 13.2.1: “Broken Hill Man,” found at Kabwe in Zambia, shows common traits associated with archaic Homo sapiens in Africa, including a large brain, taller cranium, and Homo erectus-like features such as massive brow ridges, a large face, and thick cranial bones. Credit: Homo heidelbergensis Cranium Broken Hill 1 (Rhodesian Man) by ©BoneClones is used by permission and available here under a CC BY-NC 4.0 License.

Archaic *Homo sapiens* also had a wider **nasal aperture**, or opening for the nose, and a forward-projecting midfacial region, which is later seen more fully developed among Neanderthals and is known as **midfacial prognathism**. The occipital bone often projected and the cranial bone was of intermediate thickness, somewhat reduced from *Homo erectus* but not nearly as thin as that of anatomically modern *Homo sapiens*. The postcranial skeleton remained fairly robust. Identifying a set of features that is unique to Archaic *Homo sapiens* is a challenging task, due to both individual and geographic variation—these developments were not all present to the same degree in all individuals. Neanderthals are the exception, as they had several unique traits that made them notably different from modern *Homo sapiens* as well as their closely related Archaic cousins.

The one thing that is clear about Archaic *Homo sapiens* is that, despite general features, there is a lot of regional variation, which is first seen in the different *Homo erectus* specimens across Asia and Africa. While the general features of Archaic *Homo sapiens*, identified earlier, are present in the fossils of this time period, there are significant regional differences. The majority of this regional variation lies in the degree to which fossils have features more closely aligned with *Homo erectus* or with anatomically modern *Homo sapiens*.

It is important to remember that this time period is represented by many branching relationships and assuming an evolutionary trajectory that follows a single linear path would not be correct. Even still, Archaic *Homo sapiens* mark an important chapter in the human lineage, connecting more ancestral forms, such as *Homo erectus*, to modern *Homo sapiens*. During this period of climatic transition and fluctuation, Archaic *Homo sapiens* mirror the challenges of their environments. Showing increasing regional variation due to the need for local adaptation, there is no single archetype for this group; the defining characteristic seems to be variability.

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13.2.1: The Neanderthals

One well-known population of Archaic Homo sapiens are the Neanderthals, named after the Neander Valley ("thal" in German) near Düsseldorf, Germany, where they were first discovered. Popularly known as the stereotypical "cavemen" examined at the outset of this chapter, Neanderthals have long suffered from caricature and misunderstanding. Recent research is dramatically upending these outdated beliefs, revealing that Neanderthal behavior was remarkably complex, far beyond what was exhibited by other Archaic Homo sapiens discussed in this chapter.

Here's the challenge: none of us approaches Neanderthals from a neutral perspective. Our images of them have been shaped by sensationalized museum exhibits and popular culture that portrayed them as brutish and dim-witted. To truly understand Neanderthals, we must set aside these biases and evaluate them on their own adaptive terms—not as failed versions of modern humans, but as a successful human species uniquely shaped by different evolutionary pressures. They weren't inferior; they were different, adapted to their own environmental challenges. Avoiding this "sapien-centric" perspective is essential if we want to appreciate what it meant to be Neanderthal.

What Made Neanderthals Unique?

First, it's important to understand why Neanderthals are separated from other Archaic *Homo sapiens*. Unlike the rest of Archaic *Homo sapiens*, Neanderthals are easily defined and identified in many ways. Evidence suggests the time period when Neanderthals lived was between 150,000 and 40,000 years ago. There is a clear geographic boundary of where Neanderthals lived: western Europe, the Middle East, and western Asia. No Neanderthal fossils have ever been discovered outside of this area, including Africa. This is a bit curious, as other Archaics seem to have adapted in Africa and then migrated elsewhere, but Neanderthals' regional association makes sense in light of the environment to which they were best adapted: namely, extreme cold weather. Additionally, Neanderthals have a unique and distinct cluster of physical characteristics. While a few aspects of Neanderthals are shared among some Archaic *Homo sapiens*, such as the types of tools, most Neanderthal anatomical and behavioral attributes are unique to them.

Neanderthals lived during some of the coldest times during the last Ice Age and at far northern latitudes. This means Neanderthals were living very close to the glacial edge, rather than in a more temperate region of the globe like some of their Archaic *Homo sapiens* relatives. While able to survive in arctic conditions, most Neanderthal sites dating to the glacial periods were found farther away from the severe cold, in a steppe tundra-like environment, which would have been more hospitable to Neanderthals, and their food sources, both flora and fauna (Ashton 2002; Nicholson 2017; Richter 2006).Their range likely expanded and contracted along with European glacial events, moving into the Middle East during glacial events when Europe became even cooler, and when the animals they hunted would have moved for the same reason. During interglacials, when Europe warmed a bit, Neanderthals and their prey would have been able to move back into Western Europe. Clearly, the true hallmark of Neanderthals is their adaptation to an unstable environment, shifting between warm and cold, as the climate was in constant flux throughout their existence (Adler et al. 2003; Boettger et al. 2009).

Many of the Neanderthals' defining physical features are more extreme and robust versions of traits seen in other Archaic *Homo sapiens*, clustered in this single population. Brain size, namely an enlargement of the cranial capacity, is one such trait. The average Neanderthal brain size is around 1,500 cc, and the range for Neanderthal brains can extend to upwards of 1,700 cc. The majority of the increase in the brain occurs in the occipital region, or the back part of the brain, resulting in a skull that has a large cranial capacity with a distinctly long and low shape that is slightly wider than previous forms at the far back of the skull.

Modern humans have a brain size comparable to that of Neanderthals; however, our brain expansion occurred in the frontal region of the brain, not the back, as in Neanderthal brains. This difference is also the main reason why Neanderthals lack the vertical forehead that modern humans possess. They simply did not need an enlarged forehead, because their brain expansion occurred in the rear of their brain. Due to cranial expansion, the back of the Neanderthal skull is less angular (as compared to *Homo erectus*), but not as rounded as *Homo sapiens*, producing an elongated shape, akin to a football.



Figure 13.2.1.1: Homo sapiens (left) and Neanderthal (right) skulls. Image by hairymuseummatt (original photo), DrMikeBaxter (derivative work), CC BY-SA 2.0, via Wikimedia Commons

Another feature that continues the trend noted in previous hominins is the enlargement of the nasal region, or the nose. Neanderthal noses are large and have a wide nasal aperture, which is the opening for the nose. While the nose is only made up of two bones, the nasals, the true size of the nose can be determined by looking at other facial features, including the nasal aperture, and the angle of the nasal and maxillary, or facial bones. In Neanderthals, these indicate a large, forward-projecting nose that appears to be pulled forward away from the rest of the face. This feature is further emphasized by the backward-sloping nature of the cheekbones, or the zygomatic arches. The unique shape and size of the Neanderthal nose is often characterized by the term *midfacial prognathism*—a jutting out of the middle portion of the face, or nose. This is in sharp contrast to the prognathism exhibited by other hominins, who exhibited prognathism, or the jutting out, of their jaws.

The teeth of the Neanderthals follow a similar pattern seen in the Archaic *Homo sapiens*, which is an overall reduction in size, especially as compared to the extremely large teeth seen in the genus *Australopithecus*. However, while the teeth continued to reduce, the jaw size did not keep pace, leaving Neanderthals with an oversized jaw for their teeth, and a gap between their final molar and the end of their jaw. This gap is called a **retromolar gap**.

The projecting occipital bone present in other Archaic *Homo sapiens* is also more prominent in Neanderthals, extending the trend found in Archaics. Among Neanderthals, this projection of bone is easily identified by its bun shape on the back of the skull and is known as an **occipital bun**. This projection appears quite similar to a dinner roll in size and shape. Its purpose, if any, remains unknown.

Continuing the Archaic *Homo sapiens* trend, Neanderthal brow ridges are prominent but somewhat smaller in size than those of *Homo erectus* and earlier Archaic *Homo sapiens*. In Neanderthals, the brow ridges are also often slightly less arched than those of other Archaic *Homo sapiens*.

In addition to extending traits present in Archaic *Homo sapiens,* Neanderthals possess several distinct traits. Neanderthal **infraorbital foramina**, the holes in the maxillae or cheek bones through which blood vessels pass, are notably enlarged compared to other hominins. The Neanderthal postcrania are also unique in that they demonstrate increased robusticity in terms of the thickness of bones and body proportions that show a barrel-shaped chest and short, stocky limbs, as well as increased musculature. These body portions are seen across the spectrum of Neanderthals—in men, women, and children.

Traditionally, many of the unique traits that Neanderthals possess were seen as adaptations to the extreme cold, dry environments in which they often lived and which exerted strong selective forces. For example, Bergmann's and Allen's Rules dictate that an increased body mass and short, stocky limbs are common in animals that live in cold conditions. Neanderthals were said to have matched the predictions of Bergmann's and Allen's Rules perfectly (Churchill 2006). In addition, the Neanderthal skull also exhibits adaptations to the cold. Neanderthals' large infraorbital foramina allow for larger blood vessels, increasing the volume of blood that is found closest to the skin, which helps to keep the skin warmer. Their enlarged noses resulted in longer nasal passages and mucus membranes that warmed and moistened cold air before it reached the lungs. The Neanderthals' larger nose has long been thought to have acted as a humidifier, easing physical exertion in their climate, although research on this particular

trait continues to be studied and debated (Rae et al. 2011).

New research, however, seems to suggest that these unique skeletal adaptations might not have been strict adaptations to cold weather (Evteev et al. 2017; Pearce et al. 2013). For example, large brow ridges might have served as a way to shade the face from the sun. The increased occipital portion of the brain, some researchers state, was to support a larger visual system present in Neanderthals. This visual system would have given them increased light sensitivity, which would have been useful in higher latitudes that had dark winters. And, while recent modeling of nostril airflow on reconstructed Neanderthal specimens supports the notion that Neanderthals had extensive mucus membranes inside their noses, the data shows that modern *Homo sapiens* are superior to Neanderthals in our ability to use our noses as a way to warm and cool air. However, Neanderthals were able to snort air through their noses better than we can. Why is this important? When combined with the fact that Neanderthals tended to prefer a more temperate, tundra-like environment, and that other physical traits suggest that Neanderthals had huge bodies that needed massive amounts of calories to sustain them, the picture gets clearer. Massive amounts of energy would have been required to power a Neanderthal body, and anything that might have made them more calorically efficient would have been favored. Efficient breathing, through larger noses into large lungs, meaning deeper breaths, would have been favored. To further save energy expenditure, body sizes might have been sacrificed as well. These same types of adaptations are similar to ones seen in children today who are born in high altitudes, not cold climates. Figure 13.2.1.2 provides a summary of these unique features of the Neanderthal.

Distinct Neanderthal Anatomical Characteristics

Brain size	1,500 cc average
Skull Shape	Long and low
Brow Ridge Size	Large
Nose Size	Large, with midfacial prognathism
Dentition	Reduced, but large jaw size, creating retromolar gap
Occipital Region	Enlarged occipital region, occipital bun
Other Unique Cranial Features	Large infraorbital foramina
Postcranial Features	Short and stocky body, increased musculature, barrel-shaped chest

Figure 13.2.1.2: Neanderthal distinguishing features. This table outlines key features associated with Neanderthals. Credit: Neanderthal distinguishing features table (Figure 11.6) original to Explorations: An Open Invitation to Biological Anthropology by Amanda Wolcott Paskey and AnnMarie Beasley Cisneros is under a CC BY-NC 4.0 License

A classic example of a Neanderthal with all of the characteristics mentioned above is the nearly complete La Ferrassie 1 Neanderthal, from France. This is a male skeleton, with a brain size of around 1640cc, an extremely large nose and infraorbital foramina, brow ridges that are marked in size, and an overall robust skeleton (Figure 13.2.1.3).



Figure 13.2.1.3: La Ferrassie 1 Neanderthal is representative of many classic Neanderthal features, including a large brain, large nose, large infraorbital foramina, large brow ridges, and robust postcrania. Credit: Neanderthal Skeleton Articulated by ©BoneClones is used by permission and available here under a CC BY-NC 4.0 License.

Neanderthal Culture: Tool-making and use

One key Neanderthal adaptation was their cultural innovations, which are an important way that hominins adapt to their environment. As you recall, *Homo erectus*'s tools, Acheulean handaxes, represented an increase in complexity over Oldowan tools, allowing more efficient removal of meat and possibly calculated scavenging. In contrast, Neanderthal tools mark a significant innovation in tool-making technique and use with **Mousterian tools** (named after the Le Moustier site in southwest France). These tools were significantly smaller, thinner, and lighter than Acheulean handaxes and formed a true toolkit. The materials used for Mousterian tools were of higher quality, which allowed for both more precise toolmaking and tool reworking when the tools broke or dulled after frequent reuse. The use of higher-quality materials is also indicative of required forethought and planning to acquire them for tool manufacture. It is noteworthy that the Neanderthals, unlike *Homo erectus*, saved and reused their tools, rather than making new ones each time a tool was needed.

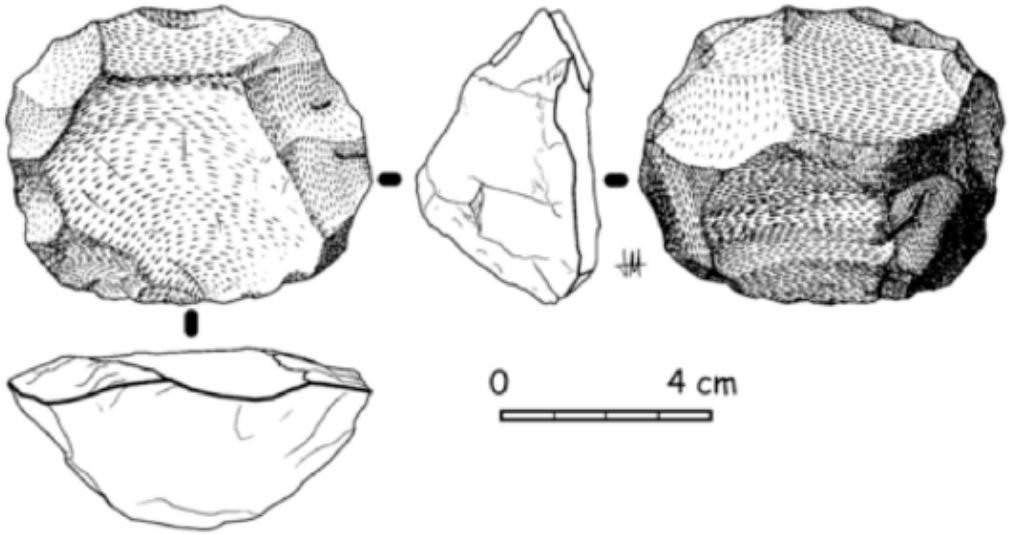


Figure 13.2.1.4: The Levallois technique is used to create Mousterian tools. The multistep process involves preparing the core in a specific way to yield flakes that can be used as tools. Credit: Nucléus Levallois La-Parrilla by José-Manuel Benito Álvarez is under a CC BY-SA 2.5 License.

Mousterian tools are constructed in a very unique manner, utilizing the **Levallois technique** (Figure 13.2.1.4), named after the

first finds of tools made with this technique, which were discovered in the Levallois-Perret suburb of Paris, France. The Levallois technique is a multistep process that requires preparing the core, or raw material, in a specific way that will yield flakes that are roughly uniform in dimension. The flakes are then turned into individual tools. The preparation of the core is akin to peeling a potato or carrot with a vegetable peeler—when peeling vegetables, you want to remove the skin in long, regular strokes, so that you are taking off the same amount of the vegetable all the way around. In the same way, the Levallois technique requires removing all edges of the **cortex**, or outside surface of the raw material, in a circle before removing the lid. The flakes, which will eventually be turned into the individual tools, can then be removed from the core. The potential yield of tools from one core would be many, as seen in Figure 11.10, compared to all previous tool-making processes, in which one core yielded a single tool. This manufacturing process might be considered the ultimate zero-waste tool-making technique (Delpiano et al. 2018).



Figure 13.2.1.5: Levallois core and flakes for tool production. Using this technique, one core is used to produce many flakes, each of which can be turned into a tool. Credit: NHM – Levalloiskern by Wolfgang Sauber (user: Xenophon) is under a CC BY-SA 4.0 License.

Neanderthal tools were used for a variety of purposes, including cutting, butchering, woodworking or antler working, and hide working. Additionally, because the Mousterian tools were lighter than previous stone tools, Neanderthals could **haft**, or attach the tool onto a handle, as the stone would not have been too heavy (Degano et al. 2019). Neanderthals attached small stone blades onto short wood or antler handles to make knives or other small weapons, as well as attached larger blades onto longer shafts to make spears. New research examining tar-covered stones and black lumps at several Neanderthal sites in Europe suggests that Neanderthals may have been making tar by distilling it from birch tree bark, which could have been used to glue the stone tool onto its handle. If Neanderthals were, in fact, manufacturing tar to act as glue, this would predate modern humans in Africa using tree resin or similar adhesives by nearly 100,000 years.

Evidence shows that raw materials used by Neanderthals came from distances as far away as 100 km. This could indicate a variety of things regarding Neanderthal behavior, including a limited trade network with other Neanderthal groups or simply a large area scoured by Neanderthals when collecting raw materials. While research on specific applications continues, it should be clear from this brief discussion that Neanderthal tool manufacturing was much more complex than previous tool-making efforts, requiring technical expertise, patience, and skills beyond toolmaking to carry out.

Neanderthal Culture: Hunting and Diet

With their more sophisticated suite of tools and robust muscular bodies, Neanderthals were better armed for hunting than previous hominins. The animal remains in Neanderthal sites show that, unlike earlier Archaic *Homo sapiens*, Neanderthals were very effective hunters who were able to kill their own prey, rather than relying on scavenging. Though more refined than the tools of earlier hominins, the Neanderthal spear was not the kind of weapon that would have been thrown; rather, it would have been used in a jabbing fashion (Churchill 1998; Kortlandt 2002). This may have required Neanderthals to hunt in groups rather than individually and made it necessary to approach their prey quite closely (Gaudzinski-Windheuser et al. 2018). Remember, the animals living with Neanderthals were very large-bodied due to their adaptations to cold weather; this would have included species of deer, horses, and bovids (relatives of the cow).

Isotopes from Neanderthal bones show that meat was a significant component of their diet, similar to that seen in carnivores like wolves (Bocherens et al. 1999; Jaouen et al. 2019; Richards et al. 2000). In addition to large prey, their diet included ibex, seals, rabbits, and pigeons. Though red meat was a critical component of the Neanderthal diet, evidence shows that at times they also ate limpets, mussels, and pine nuts. Tartar examined from Neanderthal teeth in Iraq and Belgium reveal that they also ate plant material including wheat, barley, date palms, and tubers, first cooking them to make them palatable (Henry et al. 2010). While Neanderthals' diet varied according to the specific environment in which they lived, meat comprised up to 80% of their diet (Wißing et al. 2015).

Neanderthal Culture: Caring for the Injured and Sick

While the close-range style of hunting used by Neanderthals was effective, it also had some major consequences. Many Neanderthal skeletons have been found with significant injuries, which could have caused paralysis or severely limited their mobility. Many of the injuries are to the head, neck, or upper body. Thomas Berger and Erik Trinkaus (1995) conducted a statistical comparative analysis of Neanderthal injuries compared to those recorded in modern-day workers' compensation reports and found that the closest match was between Neanderthal injuries and those of rodeo workers. Rodeo professionals have a high rate of head and neck injuries that are similar to the Neanderthals' injuries. What do Neanderthals and rodeo workers have in common? They were both getting very close to large, strong animals, and at times their encounters went awry.

The extensive injuries sustained by Neanderthals are evident in many fossil remains. Shanidar 1 (Figure 13.2.1.6a-b), an adult male found at the Shanidar site in northern Iraq and dating to 45,000 ya, has a lifetime of injuries recorded in his bones (Stewart 1977). Shanidar 1 sustained—and healed from—an injury to the face that would have likely caused blindness. His lower right arm was missing and the right humerus shows severe atrophy, likely due to disuse. This pattern has been interpreted to indicate a substantial injury that required or otherwise resulted in amputation or wasting away of the lower arm. Additionally, Shanidar 1 suffered from bony growths in the inner ear that would have significantly impaired his hearing and severe arthritis in the feet. He also exhibited extensive anterior tooth wear, matching the pattern of wear found among modern populations who use their teeth as a tool. Rather than an anomaly, the type of injuries evident in Shanidar 1 are similar to those found in many other Neanderthal fossils, revealing injuries likely sustained from hunting large mammals as well as demonstrating a long life of physical activity.

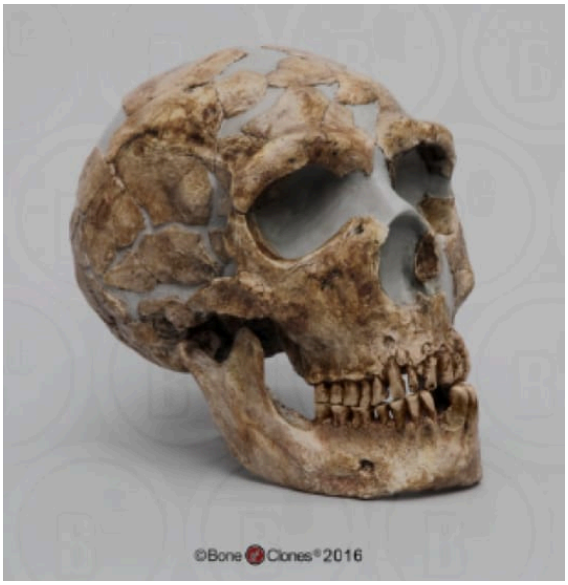


Figure 13.2.1.6*a*: The Shanidar 1 skull shows an injury to the face that would likely have caused blindness.Homo neanderthalensis Shanidar 1 Skull by ©BoneClones is used by permission and available here under a CC BY-NC 4.0 License.



Figure 13.2.1.6*b*: The Shanidar 1 right humerus (on the left side of the image) shows severe atrophy, likely due to disuse. Shanidar 1 by Chip Clark, Smithsonian Institution [exhibit: Human Evolution Evidence, Human Fossils, Species, Homo neanderthalensis] is used for educational and non-commercial purposes as outlined by the Smithsonian.

The pattern of injuries is as significant as the fact that Shanidar 1 and other injured Neanderthals show evidence of having *survived* their severe injuries. One of the earliest-known Neanderthal discoveries—the one on whom misinformed analysis shaped the stereotype of the species for nearly a century—is the La Chapelle-aux-Saints Neanderthal (Trinkaus 1985). The La Chapelle Neanderthal had a damaged eye orbit that likely caused blindness and suffered arthritis of the spine (Dawson and Trinkaus 1997). He had also lost most of his teeth, many of which he had lived without for so long that the mandibular and maxillary bones were partially reabsorbed due to lack of use. The La Chapelle Neanderthal was also thought to be at least in his mid-forties at death, an old age for the rough life of the Late Pleistocene—giving rise to his nickname, "the Old Man." To have survived so long with so many injuries that obviously precluded successful large game hunting, he must have been taken care of by others. Such caretaking behavior is also evident in the survival of other seriously injured Neanderthals, such as Shanidar 1. Long thought to be a hallmark modern human characteristic, taking care of the injured and elderly, for example preparing or pre-chewing food for those without teeth, indicates strong social ties among Neanderthals.

Neanderthal Culture: Ritual Life

Such care practices may have been expressed upon death as well. Nearly complete Neanderthal skeletons are not uncommon in the fossil record, and most are well preserved within apparently deliberate burials that involve deep graves and bodies found in specific, often fetal or **flexed positions** (Harrold 1980)**.** Discoveries of pollen in a grave at the Shanidar site in the 1960s led scientists to think that perhaps Neanderthals had placed flowering plants in the grave, an indication of ritual ceremony or spirituality so common in modern humans. But more recent investigations have raised some doubt about this conclusion (Pomeroy et al. 2020). The pollen may have been brought in by burrowing rodents. Claims of **grave goods** or other ornamentation in burials are similarly debated, although possible.

Some tantalizing evidence for symbolism, and debatably, ritual, is the frequent occurrence of natural pigments, such as **ochre** (red) and manganese dioxide (black) in Neanderthal sites that could have been used for art. However, the actual uses of pigments are unclear, as there is very little evidence of art or paintings in Mousterian sites. One exception may be the recent discovery in Spain of a perforated shell that appears to be painted with an orange pigment, which may be evidence of Neanderthal art and jewelry. However, many pigments also have properties that make them good emulsifiers in adhesive (like for attaching a stone tool to a wooden handle) or useful in tanning hides. So the presence of pigment may or may not be associated with symbolic thought; however, it definitely does show a technological sophistication beyond that of earlier Archaic hominins.

The Lasting Gift of Neanderthals: Tantalizing New Directions for Research

Examining the more recent time period in which Neanderthals lived and the extensive excavations completed across Europe allows for a much more complete archaeological record from this time period. Additionally, the increased cultural complexity such

as complex tools and ritual behaviors expressed by Neanderthals left a more detailed record than previous hominins. Intentional burials enhanced preservation of the dead and potentially associated ritual behaviors. Such evidence allows for a more complete and nuanced picture of this species.



Figure 13.2.1.7: Artistic reconstruction of Neanderthal at The Natural History Museum in Vienna, Austria. Credit: Homo neanderthalensis, The Natural History Museum Vienna, 20210730 1223 1272 by Jakub Hałun is under a CC BY 4.0 License.

Additional analyses are possible on many Neanderthal finds, due to increased preservation of bone, the amount of specimens that have been uncovered, and the recency in which Neanderthals lived. We should be cautious, however, to consider the potential bias of many Neanderthal sites. Overwhelmingly, Neanderthal skeletons are found complete, with injuries or evidence of disease in caves. Does this mean all Neanderthals lived a tough, disease-wrought life? Probably not. It does, however, indicate that the sick were cared for by others, and that they lived in environments that preserved their bodies incredibly well. These additional studies include the examination of dental calculus and even DNA analysis. While limited, samples of Neanderthal DNA have been successfully extracted and analyzed. Research thus far has identified specific genetic markers that show some Neanderthals were light-skinned and probably red-haired with light eyes. Genetic analyses, different from the typical hominin reconstruction done with earlier species, allow scientists to further investigate soft tissue markers of Neanderthals and other more recent hominin species. These studies offer striking conclusions regarding Neanderthal traits, their physical appearance, and their culture, as reflected in these artists' reconstructions (Figure 13.2.1.7).

Paleogeneticist Profile: Dr. Svante Pääbo



Figure 13.2.1.8: 2022 Nobel Prize Winner, Dr. Svante Pääbo

Dr. Svante Pääbo (Figure 13.2.1.8), of the Max Planck Institute for Evolutionary Anthropology, has been at the forefront of much of this new research, largely in the form of genomic studies (The Nobel Prize 2022). Awarded the Nobel Prize for Physiology or Medicine in 2022, Pääbo is known primarily for his work with ancient DNA. He has successfully sequenced mitochondrial DNA (mtDNA) as well as the entire Neanderthal genome from nuclear DNA. His genomic work has led to the realization that Denisovans are genetically distinct from Neanderthals, as well as the recent identification of a Neanderthal father and teenage daughter, which he discovered by looking for unique DNA markers in the fossil record. Additionally, Pääbo's genomic work has provided researchers with additional lines of evidence regarding the connections between hominin fossils (such as Neanderthals) and modern people, their time of divergence, and current genetic overlap. The work of Pääbo has even formalized a new field of study within anthropology—paleogenomics. To stay up to date with Dr. Svante Pääbo's work, be sure to follow his lab's website.

Neanderthal Culture: Communication

To successfully live in groups and to foster cultural innovations, Neanderthals would have required at least a basic form of communication in order to function, possibly using a speech-based communication system. The challenge with this line of research is that speech, of course, is not preserved, so indirect evidence must be used to support this conclusion. It is thought that Neanderthals would have possessed some basic speech, as evidenced from a variety of sources, including throat anatomy and genetic evidence (Lieberman 1971). There is only one bone in the human body that could demonstrate if a hominin was able to speak, or produce clear vocalizations like modern humans, and that is the hyoid, a U-shaped bone that is found in the throat and is associated with the ability to precisely control the vocal cords. Very few hyoid bones have been found in the archaeological record; however, a few have been uncovered in Neanderthal burials. The shape of the Neanderthal hyoid is nearly identical to that of modern humans, pointing to the likelihood that they had the same vocal capabilities as modern humans. In addition, geneticists have uncovered a mutation present in both modern humans and Neanderthals—the FOXP2 gene—that is possibly linked to the ability to speak. However, other scientists argue that we cannot make sweeping conclusions that the FOXP2 gene accounts for speech due to small sample size. Finally, scientists have also pointed to the increasingly complex cultural behavior of Neanderthals as a sign that symbolic communication, likely through speech, would have been the only way to pass down the skills needed to make, for example, a Levallois blade or to position a body for intentional burial.

Neanderthal Intelligence

Understanding Neanderthal intelligence requires moving beyond simple comparisons of brain size. While Neanderthals possessed large brains (larger, on average than a modern human, brain volume alone doesn't determine cognitive ability (Alex 2018). What matters more is how the brain is organized and what it's optimized to do. The archaeological record demonstrates that Neanderthals were intellectually sophisticated: they created complex tools, developed cultural practices, and showed

compassion toward their community members, all markers of advanced cognition.

Recent neurological research reveals that Neanderthal brains were structured differently from modern human brains, reflecting different cognitive priorities. Pearce and colleagues (2013) found that while Neanderthals and modern humans had nearly identical frontal lobes, Neanderthals possessed a significantly larger visual cortex—the region dedicated to processing visual information. This enhanced visual processing would have been crucial for navigating the challenging Ice Age landscapes they inhabited.

Geneticist John Blangero's research team (2014) identified additional structural differences in Neanderthal brains, particularly in regions associated with information processing, emotional regulation, and neural connectivity. Rather than interpreting these as limitations, we should recognize them as evidence of a different cognitive architecture. As Blangero noted, "Neanderthals were certainly cognitively adept" (qtd. in Wong 2015), though their mental strengths may have been channeled differently than ours. For instance, enhanced visual-spatial processing and individual survival skills may have been prioritized over the neural networks that facilitate large-scale social coordination in modern humans (el-Showk 2019; Cassanova and Feltus 2025).

In essence, Neanderthal brains were specialized for a different ecological niche and social structure. Their cognitive toolkit was adapted to the specific demands of Ice Age Europe, just as modern human cognition evolved to meet different challenges.

Developmental Differences

Finally, Neanderthals followed a distinct pattern of brain and body development after birth. Their babies matured along a different trajectory than modern human infants, with brain expansion and physical growth progressing at different rates (Smith et al. 2010; Zollikofer and Ponce de León 2013). Neanderthal childhood appears to have been shorter, with individuals reaching physical and cognitive maturity more quickly. This accelerated development may have been adaptive in their challenging Ice Age environments—producing capable hunters and gatherers at younger ages could have been a survival advantage when resources were scarce and life was precarious.

However, this developmental pattern came with trade-offs. The extended childhood that characterizes modern humans allows for prolonged periods of play, experimentation, and creative problem-solving without immediate survival pressures. A shorter childhood may have limited opportunities for this kind of cognitive flexibility to develop (Nowell 2016). Rather than viewing Neanderthal development as simply "less" than ours, we should recognize it as a different adaptive strategy—one that prioritized rapid maturation in a harsh environment, though it may have constrained certain types of innovation.

Evidence of Neanderthal cognitive sophistication can be found in their brain lateralization—the specialization of different brain hemispheres for different functions. Neanderthals exhibited clear limb asymmetry and hand dominance, as revealed by wear patterns on their stone tools (Frayer et al. 2012). Their teeth provide even more compelling evidence: when Neanderthals used the "stuff-and-cut method" of eating, which involved holding meat in their teeth, pulling it taut with one hand, and cutting with their dominant hand, they left distinctive wear marks. Analysis of 17 Neanderthal specimens shows that 15 were right-hand dominant, a pattern strikingly similar to modern human populations.

This handedness is significant because it indicates bilateral brain development, a neurological feature associated with complex cognitive functions including language. In modern humans, hand dominance correlates with the brain's language centers. The presence of consistent handedness in Neanderthals strongly suggests they possessed the neural architecture necessary for sophisticated communication and possibly speech. Rather than viewing Neanderthals as cognitively limited, this evidence positions them as having the neurological foundations for complex symbolic thought and social communication which are key markers of advanced intelligence in any human species.

What Happened to the Neanderthals?

Around 40,000 years ago, Neanderthals vanished from the fossil record. For thousands of years before that, they shared Europe with our direct ancestors—modern humans who had expanded out of Africa around 150,000 years ago. We even know they occasionally interbred; modern Europeans and Asians carry 1-4% Neanderthal DNA, while sub-Saharan Africans don't. Despite this mixing, Neanderthals ultimately went extinct. Why?

The Leading Hypotheses

Climate Chaos

As the climate swung between warming and cooling periods, the large cold-adapted animals that the Neanderthals hunted either migrated north or died out. A shrinking food supply became even more problematic when modern humans arrived to compete for the same resources (Defleur and Desclaux 2019; Staubwasser et al. 2018).

Volcanic Catastrophe
A massive volcanic eruption 40,000 years ago may have disrupted plant growth and altered local climates, reducing temperatures and shortening growing seasons right when Neanderthals were already struggling (Golovanova et al. 2010).

Brain Differences
Recent genetic studies suggest Neanderthal brains may have developed differently at the cellular level, possibly faster but with more neural misfires and less organized processing. This could have limited their ability to innovatively solve problems when their environment changed rapidly (Mora-Bermúdez et al. 2022; Pearce et al. 2013; Trujillo et al. 2021).

Reproductive Challenges
A number of studies have looked at how the Neanderthals faced several reproductive disadvantages (Weaver and Hublin 2009; Mendez et al. 2016; Degioanni et al. 2019):

- Females may have reached sexual maturity later than modern humans
- Childbirth was extremely difficult
- Males may have carried a genetic marker that caused fetal-maternal incompatibility during pregnancy
- Even small but continuous fertility problems could doom a small population

Competition with Modern Humans
When modern humans arrived in Europe, competition intensified. Neanderthals needed slightly more calories than modern humans—a small difference that could prove fatal when resources were scarce. Modern humans may have also brought new diseases that decimated Neanderthal populations (Churchill et al. 2009; Gilpin et al. 2016; Houldcroft and Underdown 2016; Venner 2018). The nature of the interactions between these two different yet not so different types of humans remains one of anthropology's most intriguing puzzles.

The Bottom Line

With populations estimated at only 5,000-70,000 individuals, Neanderthals were vulnerable. Most likely, it wasn't just one factor but a combination of environmental stress, biological limitations, and competition with modern humans that sealed their fate. The mystery continues to unfold as researchers discover more evidence about our closest extinct relatives.

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13.2.2: The Denisovans

Meet the Extreme Altitude Survivors of Asia

While Neanderthals represent one regionally adapted branch of the Archaic *Homo sapiens* family tree, recent discoveries in Siberia and the Tibetan Plateau surprised paleoanthropologists by revealing yet another population that was contemporary with Archaic *Homo sapiens*, Neanderthals, and modern *Homo sapiens*.



Figure 13.2.2.1: Reproduction of Denisovan molar. Credit: Denisova Molar by Thilo Parg is under a CC BY-SA 3.0 License.

When geneticist Svante Pääbo and his team analyzed DNA from a child's finger bone and an adult molar (Figure 13.2.2.1) that had been uncovered, they found something unexpected. The mitochondrial and nuclear DNA sequences showed that these individuals were genetically distinct from both Neanderthals and modern humans. Named "Denisovans" after the cave where they were found, this population turned out to be more closely related to Neanderthals than to us. In fact, the evidence suggests that Neanderthals and Denisovans shared a common ancestor who first split from the modern human line, and only later did the Neanderthal and Denisovan populations diverge from each other (Reich et al. 2010).

A Hidden Legacy in Our Genes

Here's where the story gets personal: if you have ancestry from Melanesia, aboriginal Australia, or Polynesia, you likely carry up to 5% Denisovan DNA. Even people with Asian or Native American ancestry carry traces—about 0.2%—of Denisovan genes (Figure 13.2.2.2). Research suggests that modern humans and Denisovans interbred at least once, and possibly twice, at different points in prehistory (Vernot et al. 2018; Browning et al. 2018).

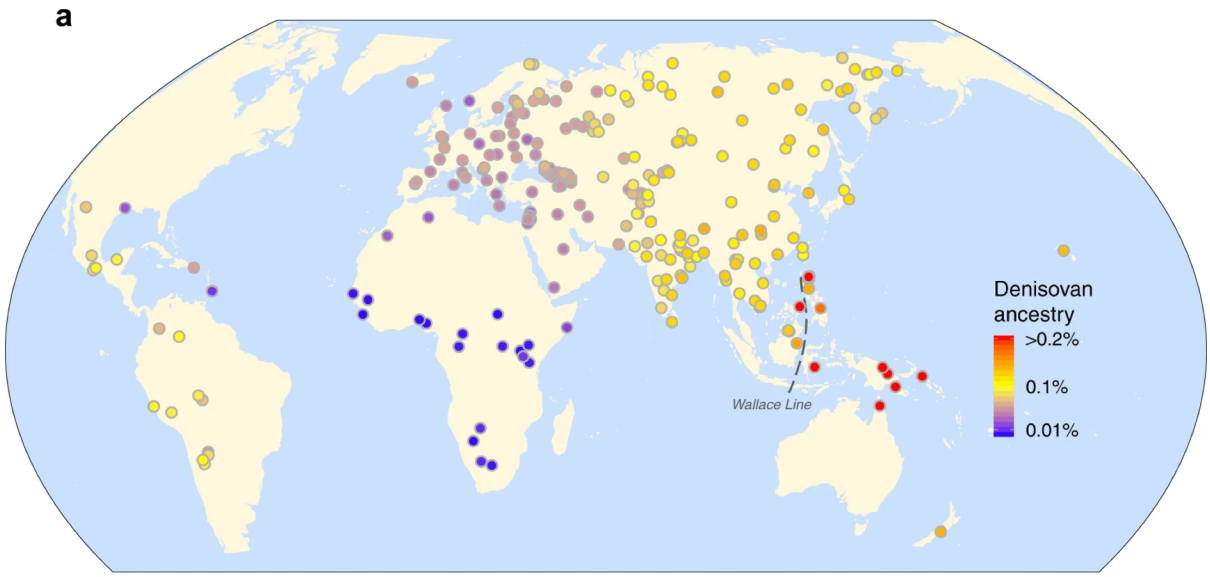


Figure 13.2.2.2: Archaic introgression in modern humans across the world (Denisovan only) by Kai Yuan et al., CC BY 4.0 via Wikimedia Commons

High Altitude "Sur-thrivers"

Genetic analysis has revealed another interesting finding about Denisovans: they possessed special adaptations that allowed them to thrive at extreme altitudes. In places like Tibet—where temperatures average near freezing and the elevation exceeds 4,000 feet above sea level—most people would suffer from altitude sickness and hypoxia (oxygen deprivation). But Denisovans, possibly comprising three distinct populations, had evolved to handle these harsh conditions.

How do we know they lived in Tibet? Protein analysis of a Denisovan jawbone places them there as early as 160,000 years ago (Chen et al. 2019). Even more intriguingly, genetic evidence shows that modern Tibetan populations interbred with Denisovans between 30,000 and 40,000 years ago. This means that the unique high-altitude adaptations that help modern Tibetans live comfortably at extreme elevations may be a genetic gift from their Denisovan ancestors (Huerta-Sanchez et al. 2014).

Recent discoveries continue to expand our understanding of where Denisovans lived and how far they traveled. Stone tools similar to those found in a Denisovan cave in Siberia have been discovered on the Tibetan Plateau, suggesting connections between Denisovan populations across vast distances (Zhang et al. 2018). In Laos, researchers found a molar from a young girl—possibly Denisovan—that shows strong similarities to specimens from China (Demeter et al. 2022). But perhaps most fascinating is the DNA analysis from Denisova Cave that revealed the genome of an individual whose parents were from different human populations: a Neanderthal mother and a Denisovan father (Slon et al. 2018). This mixed parentage individual suggests that these archaic human groups didn't just coexist—they formed families together.

While researchers continue to interpret these findings, each discovery reveals new possibilities about our complex human family tree. The story of the Denisovans reminds us that human evolution wasn't a simple, linear progression but rather a rich network of populations that separated, reconnected, and shaped who we are today. To follow the latest discoveries in this rapidly evolving field, consider checking out the Smithsonian's Human Origins Program on social media.

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13.2.3: Five Human Species You May Not Know About

By Anna Goldfield

22 Sep 2021

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We're so used to the idea of being the only people around that it seems outlandish to think that not so long ago in our evolutionary history, multiple types of humans occupied various landscapes. The environments of the Paleolithic, or Stone Age, were dynamic. Populations moved, interacted, and sometimes even interbred. As archaeological methodologies and available technologies become more sophisticated, we're able to "see" the lives of these human populations with more and more nuance, making the world of the Paleolithic more like a living tableau than a frozen museum diorama.

So, how many different types of humans have there been? It's a big question, and anthropologists have yet to agree on an answer.

A big part of the debate is that there are very few specimens for anthropologists to work from. Take a moment to picture the whole spectrum of modern humans' body sizes and shapes, and imagine trying to re-create that using the skeletons of just a handful of random individuals. Researchers have unearthed fossils from about 6,000 hominins in total. Only a handful have yielded any genetic evidence.

Researchers try to work out which ones represent novel species, sometimes from a single skull or just a finger bone. The work is hard and can be contentious.

Each scientific name bears a genus term followed by a species term. In the human family tree, the genus *Homo* goes back about 3 million years and includes more than a dozen named hominin species (including modern humans, *H. sapiens*). The extended hominin family, including the genus *Ardipithecus*, goes back some 6 million years.

Here are five hominins who contributed to the story of human evolution that you may be less familiar with, showing just how diverse the ancient human landscape has been.

1. *Homo rudolfensis*

Homo rudolfensis is a perfect example of the pitfalls of describing a species based on limited fossil evidence. The designation is based on a single specimen—a skull (also known as the less snappy KNM-ER 1470) dated to about 1.9 million years ago from the site of Koobi Fora in what is today Kenya.

Originally, the skull was attributed to the species *Homo habilis*, the earliest-known member of the human genus. There were a few problems with this, though. First, the braincase of the skull was quite big. The other existing *H. habilis* specimens had brains around 500 cubic centimeters; *H. rudolfensis* had a cranium that would have accommodated about 700 cubic centimeters of brain. The *H. rudolfensis* specimen also has larger teeth and a smaller brow ridge than other *H. habilis* skulls.

Anthropologists eventually concluded that variation within a single species—even accounting for possible differences between males and females—was unlikely to explain these physical differences, and KNM-ER 1470 was given a separate species designation in 1986.



Figure 13.2.3.1: Casts of *Homo rudolfensis* (left) and *Homo habilis* (right), both found in Kenya, showcase some variation in hominin skull shape and size. Image Credit: *Gunnar Creutz/Wikimedia Commons*

2. *Homo antecessor*

The Gran Dolina Cave in Atapuerca, Spain, is a massive archaeological site, with deposits that extend down almost 20 meters and span more than half a million years. The oldest of these deposits date to around 780,000 years ago and include the remains of a hominin group that was called *Homo antecessor* in 1997.

The species is often described as having a mix of modern and "primitive" traits—some features are similar to those of Neanderthals and Denisovans, while others are more like *Homo sapiens*. A recent study of ancient proteins extracted from the dental enamel of one of the Atapuerca fossils has confirmed that *H. antecessor* is a very closely related "sister lineage" to modern humans, Neanderthals, and Denisovans. All of these populations share a close common ancestor.

3. *Homo floresiensis*

The only known fossils of *Homo floresiensis* come from Liang Bua Cave on the Indonesian island of Flores. Anthropologists also refer fondly to the species as "hobbits" due to their diminutive size: They would have stood a bit over 3 feet tall. The first remains of *H.* floresiensis were discovered in 2003.



Figure 13.2.3.2: Cave where the remains of *Homo floresiensis* were discovered in 2003, Liang Bua, Flores, Indonesia [2007]. Image credit: Rosino, CC BY-SA 2.0 via Wikimedia Commons

These human relatives had small brains (around 400 cubic centimeters) but hunted prey on the island and made tools very similar to those made by *Homo erectus*, a species with much larger brains. A possible explanation for the hobbits' small stature is a phenomenon known as insular dwarfism**.** In environments with constrained resources—like an island surrounded by open ocean—species that would normally have larger body and brain sizes tend to evolve toward smaller body mass and smaller brains. A species of pygmy elephant (now extinct) that once shared the island of Flores with *H. floresiensis* is an example of the same process.



Figure 13.2.3.3:The skeleton of a *Homo floresiensis* woman at the Natural History Museum in London, England. Image credit: Emőke Dénes, CC BY-SA 4.0 via Wikimedia Commons

4. *Homo luzonensis*

Another recently discovered island-dwelling hominin population, *Homo luzonensis* lived on the island of Luzon in the Philippines around 50,000–60,000 years ago. This species is represented by just 13 bones—teeth, finger, and toe bones, and a femur. These belonged to at least three different individuals.

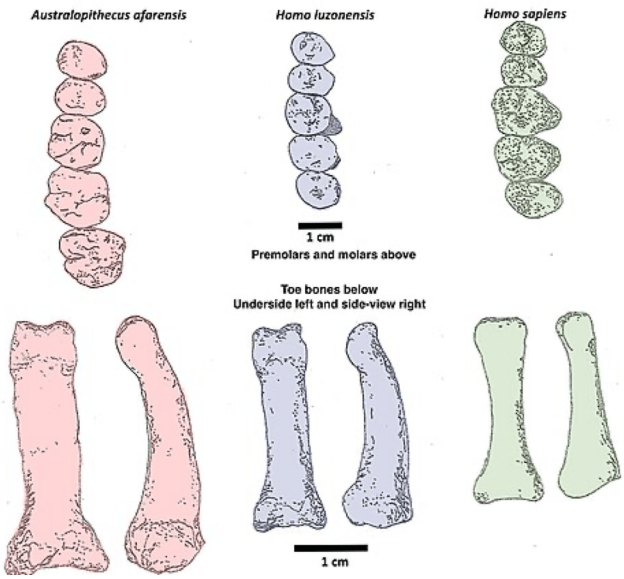


Figure 13.2.3.4: Subtle differences in teeth and toe bones can help set two hominin species apart.
Credit: Homo schollensis, CC BY-SA 4.0 via Wikimedia Commons

In 2019, anthropologists determined that these bones are different enough from species like *H. erectus* and *H. floresiensis* to warrant a new species category. The finger and toe bones of *H. luzonensis* are especially interesting. They're slightly curved, a feature that is shared by living species of tree-dwelling primates. This suggests that for *H. luzonensis*, living in the trees might still have been a part of their lifestyle.

5. *Homo Longi* ("Dragon Man")



Figure 13.2.3.5: Facial reconstruction of *Homo longi* based on forensic approximation by Cicero Moraes, CC BY-SA 4.0 via Wikimedia Commons

The most recently proposed hominin species comes from China, where the heavy-browed skull nicknamed "Dragon Man" was named in June. The skull was first found in the 1930s but only recently made available to scientists for analysis. It has been dated to around 146,000 years ago and is touted by its analyzers as a "long-lost sister lineage" of *H. sapiens*.

The eye sockets of the skull are large and blocky, the molars are sizeable (much larger than yours or mine), and the ridge over the eyes is massive. All of these are more "primitive" traits. However, the brain size is comparable to that of modern humans. This new discovery is another reminder of the difficulty of assigning a single specimen to a new species. The Dragon Man may in fact be a Denisovan—so far there's no genetic evidence to help determine that. Wherever this individual fits on the human family tree,

it's an exciting reminder that the human past is a tangled one, and we've still got so much to learn.

For more of the story on some of the most recently discovered members of our extended ancient family, check out the "Who's the New Guy" episode at The Dirt Podcast *brought to you by* SAPIENS.

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13.3: Becoming Human

The Human Revolution

In the previous chapters, we discussed human features that appeared in the paleoanthropological record: bipedalism, big brains, hunting, stone-tool making, fire and cooking. We now turn to the question of when and where other human features first appeared—storytelling, music, bodily decoration, and belief in the **Supernatural**. That is, when, where, and why did we become truly human?

Anatomically modern humans (AMH's) appear in the fossil record around 200,000 years ago in Africa. Evidence for the full spectrum of human behavior, however, doesn't appear in the record until around 40,000 years ago. The shift to modern human behavior, with our interest in art, ritual, games, stories, music, language, and symbolic thought, is sometimes called the Human Revolution, the emergence of the modern human mind. The lag between physical modernity and cognitive modernity is likely due in part to problems of preservation and the sparseness of early human populations. Thus, the emergence of the modern human mind probably occurred long before we see it in the archaeological record.

The Upper Paleolithic

All people living in the Pleistocene (2.8 **mya**—12 **kya**), the last ice ages, were **hunter-gatherers**, living off wild non-domesticated foods. No one was farming or herding in the Pleistocene. While the philosopher Hobbes characterized the hunter-gatherer lifestyle (man in a state of nature) as "poor, nasty, brutish, and short," life during the Pleistocene may have been one of relative abundance and health, especially compared with some later farming communities. The humans that lived at this time may have been the *original*, original affluent society. The very earliest glimmers of modern human behavior and thought occur in Africa. Fittingly, one of the earliest pieces of evidence of a modern human mind is a kind of crayon. The decorated block of red ocher, a mineral pigment, was discovered at Blombos Cave in South Africa and dates to 75,000 years ago. More recently, abalone shells filled with red ocher have been found at Blombos dating to around 100,000 years ago—perhaps the remains of an early artist's palette. People were likely painting, scarring, and tattooing their bodies long before we find evidence for it in the archaeological record given the vagaries of preservation.

While the earliest examples of modern behavior occur in Africa, some of the most spectacular preservation of early modern humans occurs during an archaeological time period called the Upper Paleolithic (around 40 kya -12 kya), or Upper Old Stone Age, in Europe. (Note that the Upper Paleolithic describes a human time period, whereas the Pleistocene describes a geological one). The reasons for this are several. First, modern archaeology was born in Europe in the 18th and 19th centuries. Europe was where the archaeologists were and they studied sites in that region because they were available. Secondly, there are numerous caves and rock shelters (rocky overhangs) in Europe; these are perfect containers to protect and preserve archaeological remains. Finally, environmentally, the European subcontinent was in a climate zone during the last ice age that supported vast herds of grazing animals. These animals in turn supported a relatively dense population of humans, who in turn left a plentiful archaeological record.

A number of innovations become apparent in the Upper Paleolithic archaeological record that indicate the full spectrum of totally modern human mind. These include: art, elaborate burial, sewn clothing, jewelry, and ritual. These are the hallmarks of modern behavior. These features indicate that these were people like us, not only in their physical appearance, but intellectually, behaviorally, and emotionally.

During the Pleistocene, Europe was inhabited by very large animals, or megafauna, including mammoth, woolly rhinos, giant cave bears, bison, along with wild horses, caribou, cattle and lions. Upper Paleolithic people were hunting some of these animals and reliant on terrestrial and aquatic animal protein. There is less evidence of plant consumption, though plants were likely a part of the diet as well.



Figure 13.3.1: Modern humans were living alongside Pleistocene megafauna in Europe and elsewhere. "**Mammoth of BC**" by Tyler Ingram is licensed under CC BY NC-ND 2.0

Technological Innovations

Neanderthals and even *Homo erectus* had fairly sophisticated tools, and were able to hunt and make fire. But with modern humans, there was an explosion of creativity. An innovation that became prevalent in the Upper Paleolithic was the **atlatl** or spear thrower. This weapon is essentially a stick that propels a long dart. This technology allowed humans to increase the force behind their weaponry as well as get some distance between themselves and their prey. The atlatls of the Upper Paleolithic were sometimes beautifully decorated with Pleistocene megafauna. The atlatl proved to be a useful weapon and it use lasted into the modern age. Spanish conquistadors, for example, encountered Aztecs equipped with obsidian-edged atlatl darts.

While "cave people" are often depicted wearing simple animal skins and furs, needles found on Upper Paleolithic sites indicate that people wore tailored clothing. Having to live and survive in the colder temperatures of the Pleistocene, people were by necessity highly skilled at making clothing from animal skin. Some figurines that date to this time also suggest sewn clothing. A series of burials at Sungir (around 28,000 years ago) in Russia were covered in tens of thousands of mammoth ivory beads, which appear to have been sewn onto garments that did not survive. At other Upper Paleolithic sites dating around 25,000 years ago, people were buried wearing necklaces of arctic fox teeth and shell. Like people today, Upper Paleolithic people were concerned about their appearance, and very likely used symbolic markings, body decoration, and clothing to differentiate between people of different groups, just as we do today.



Figure 13.3.2: Scene from Lascaux Cave Exhibit at the Houston Museum of Natural History. Image credit: Randall Pugh, Flickr is licensed under a CC BY-NC-SA 2.0

Art and Music

The instinct to express oneself musically is very old. Early bone and ivory flutes have been found in European caves dating to around 30,000 years ago. Considering that these instruments were found in caves, the sound of the flutes would have been amplified by sound waves bouncing off the cave walls. Bullroarers have also been discovered in Upper Paleolithic contexts. These are instruments consisting of a thick piece of shaped wood attached to a cord. When swung in a circle, the bullroarer makes a haunting sound that can travel long distances.

YouTube Video

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Priscilla Hernandez. (2015, October 2).*Priscilla Hernandez- Playing and chanting with a wind band roarer*. [Video]. YouTube. https://youtu.be/6sjKeFthAhM?si=NYi8EDxabX6LSmti

Historically bullroarers have been used around the world—Australia, Ireland, North America, and elsewhere—for ceremonies and entertainment. In traditional societies, music is not just entertainment, but tied to ritual. By making music together and dancing, people often develop a sense of collective effervescence and unity.

While the first indications of decorative art occur much earlier and there are even a few possible **Neanderthal examples (Davidson 2014),** representational art appears for the first time in the Upper Paleolithic and equivalent time periods in Asia. In contrast to purely decorative art, representational art resembles something in the physical world. Caves of southern France and northern Spain contain images of Pleistocene horses, ibex, mammoth, rhinos, lions, bears, and even a great auk.



Figure 13.3.3: Aurochs, horses and deer painted on a cave in Lascaux, France. Image Credit: EUX, Public domain, via Wikimedia Commons

The most famous of these caves is Lascaux (pronounced Las-CO) in Southern France dating to around 17,000 years ago. Like so many archaeological sites, it was not found by archaeologists but by curious teenagers exploring the countryside. With 600 paintings and 1,500 engravings, Lascaux contains the largest collection of ice-age art anywhere. For that reason, and for the delicacy and beauty of the images, it was placed on the United Nations Educational, Scientific, and Cultural Organization (UNESCO) list of World Heritage Sites. These are cultural sites around the world that are considered to have universal value for humanity.

Another famous Upper Paleolithic site, discovered by a young girl named Maria de Sautuola, is Altamira in Spain. One of the panels is 45 feet in length. These panels were not one-time paintings, but "touched up" and added to with overlapping images over time. This layering effect is called a *palimpsest*. The term palimpsest is often used to refer to paper that has been reused, a common practice in Medieval times. Upper Paleolithic artists used the contrast between dark and light pigments (charcoal, ocher and hematite) to create a sense of three-dimensionality. This effect is called *chiaroscuro*. The paintings are so surprisingly sophisticated for their time that when the Spanish artist Pablo Picasso looked upon the paintings at Lascaux he remarked, "We have invented nothing."

Both Lascaux and Altamira were opened to the public in the mid-1900s. Tourists, however increased the temperature of the cave as their exhalations contained both water vapor and carbon dioxide. Carbon dioxide is of course the greenhouse gas that we are all familiar with that traps heat and causes atmospheric temperatures to rise. Trapped inside the cave, these gasses led to a kind of "caval warming," ripe for the growth of mold, algae, and bacteria. Both caves were closed to large numbers of visitors and they have since stabilized. Replicas of parts of both caves called Lascaux II and Altamira II have been created to give tourists a sense of the actual site.

We are so used to electricity that it is easy to forget that these were completely pitch black caves. Lascaux alone contained 150 animal fat lamps that were used to light the interiors of the caves. Remember, control of fire had occurred long before, at least by 350,000 years ago in Europe by Neanderthals and much earlier elsewhere. The light in the cave would have flickered, perhaps giving the animals a sense of motion. One creative soul has put together overlapping images of Upper Paleolithic art that is much like a cartoon flip book, giving life and motion to these ancient creatures. That is, these images could potentially have acted as early movies, probably accompanied by that quintessentially human compunction—storytelling.



Figure 13.3.4: **Animal fat lamp from Lascaux** by **Sémhur** is licensed under CC-BY-SA-4.0

Paintings are not just located on the walls of the caves, but also on the ceilings. People would have had to build some kind of scaffolding, much like Michelangelo's work on the Sistine Chapel. Indeed, there are indentations in the walls of the caves that likely held support for the scaffolding.

Portable Art

In addition to the cave art, there is an abundance of portable art. These, of course, qualify as artifacts, being transportable from place to place. Upper Paleolithic artists excelled at depicting animals in all their earthy glory. In one instance, an herbivore (chamois) is either defecating or perhaps giving birth as a bird perches near its behind. Another very famous example of portable art is the lion-man/woman (Figure 13.3.5). The artifact combines both human elements (like bipedalism or walking on two legs) and lion elements, embodying that human ability to create new realities.



Figure 13.3.5:The lion man from the Stadel Cave in Hohlenstein, Lonetal by Dagmar Hollmann, CC BY-SA 4.0 via Wikimedia Commons

While portraits, or depictions of actual people, are uncommon, there are about 200 known "Venus figurines" or woman figures (Thurman 2015). (The term Venus figurine is not used in some circles to avoid assuming that the figurines represented goddesses). These are voluptuous female bodies made from clay, ivory, and stone. There is little attention paid to the face, head, and extremities. The interest is in the body—the breasts, buttocks, and belly. Several of these figurines appear to be pregnant

with an everted navel. The earliest representational art in Europe is a **Venus of Hohle Fels** in Germany dated to around 35–45 thousand years ago. There are also woman figures in cave art that use that natural topography of the cave to indicate the pregnant belly and vulva.



Figure 13.3.6: Two views of the Venus of Hohle Fels figurine, which may have been worn as an amulet, and is the earliest known, undisputed example of a depiction of a human being. Image copyright H. Jensen / Universität Tübingen featured on Wikipedia and used under Fair Use guidelines.

But what do these figures mean? Some Venus figurines, like the Venus of Hohle Fels, contain traces of red ocher, possibly suggesting a ritual rather than functional nature. Others have suggested that the figurines are an effort to cope with the dangers of childbirth or were a fertility fetish. Still others suggest they depict an early European goddess. Venus figurines, however, span thousands of years and a wide area from Western Europe to Siberia. Determining the meaning of something that spans that kind of time and space is challenging. We know that symbols in our own culture can change in meaning over just a few generations, so imagine the possible varied meaning Venus figurines might have had over thousands of years.

From Wild Wolves to Best Friends: The Origins and Significance of Dog Domestication

Another important event associated with the Upper Paleolithic is dog domestication. Dogs were the first species to be domesticated by humans, plant or animal. Dogs throughout the ages have provided much for humans including help in hunting, herding, guarding, warmth, food, hauling materials, sacrifices, and companionship. At the ice-age site of Predmosti, Moravia, a dog skull was found with a mammoth bone in its mouth suggesting dog domestication is very ancient. But what is domestication? Domestication has two meaning really, but both are defined with respect to humans. One simply means tame and friendly to humans. But it has a more technical meaning as well. Domestication means that traits are selected for by humans resulting in changes to the genome of an organism. Dogs were domesticated from wolves (*Canis lupus*). Some argue that wolves were kept as pets and the more docile ones bred. Others, like Ray Coppinger, disagree. Coppinger thinks that this manner of domestication was just not feasible for Paleolithic humans. Instead, he thinks that more docile and “tame” wolves tended to hang around human settlements. The food these animals obtained provided them with a selective advantage, thereby allowing them to survive and reproduce at a greater rate than wolves who did not venture near human settlements. Coppinger says that in effect, dogs were self-domesticated. In this regard, dogs both experienced a change in the genome and also became more friendly to humans. Recent research has begun to pinpoint the genes that make dogs so sociable. The genetic area affected also interestingly is affected in people with Williams-Beuren Syndrome. People with this syndrome tend to be indiscriminately friendly.

The Friendly Foxes

One of the most fascinating studies that reflects on dog domestication is the silver-fox experiment. In 1959, Dmitry Belyaev conducted a study on silver foxes of Siberia who were being bred for their fur. Belyaev bred the docile foxes (1% of the population)

with each other, being careful not to inbreed them. After just a few generations, not only did Belyaev have very friendly, even pet-worthy foxes (though they can be unpredictable), but he noticed other morphological changes as well. The foxes' ears became floppier, their coats became patchier, their muzzles shortened, their teeth were smaller, their tails wagged, and they began to vocalize and play. In essence, they were retaining juvenile fox physical traits—called *neoteny*—just by selecting for friendly behavior. Other domesticated animals show similar neotonic, that is juvenile, traits in adulthood.

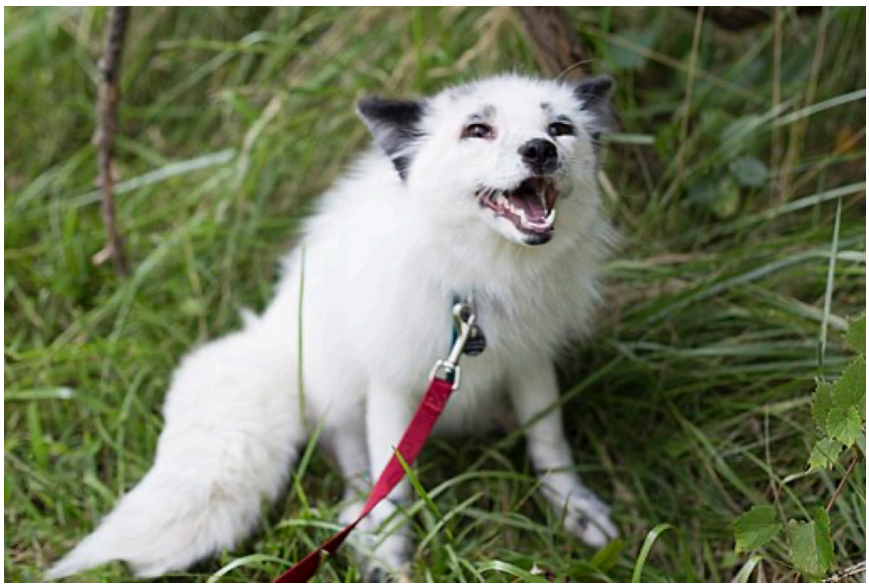


Figure 13.3.7: A Russian domesticated Red Fox with "Georgian White" fur color. Image credit: Kayfedewa at English Wikipedia, CC BY 3.0 via Wikimedia Commons

Something similar may have happened in dogs, whether the traits we selected by humans or a result of self-domestication. That is, dogs are essentially wolves that retain juvenile characteristics. Why are dogs so important to discuss in an anthropology class? Paleoanthropologist Pat Shipman (2015) has argued that we humans owe dogs a lot. She proposes that it was dog domestication that allowed us to out-compete archaic humans like Neanderthals, who had complex tools, fire, and hunting prowess. What they lacked, she argues, was early dogs, "wolf dogs" as she calls them. Aside from companionship, dogs provide warmth, protection, can haul items, help humans hunt, and in a pinch, can be eaten. Dogs would especially have been useful for hunting. Anthropologist Richard Lee noted that among the Bushmen, the man who owned a pack of dogs brought in 75 percent of the meat.

Not only do dogs provide a window into the success of early modern humans, but they might just be the key to understanding humans in a more general sense. Some scholars argue that humans, like dogs, self-domesticated (Hare and Woods 2020). In effect, there was a selective advantage to neoteny in humans, retaining juvenile traits. Some think that it is our playful nature, our child-like curiosity that won the day over archaic humans.

The Ultimate Invasive Species

Paired with their new canine counterparts, humans became a strong selective force in shaping the fate of the species around them. Pat Shipman argues that *Homo sapiens* should be considered an invasive species, and the late Pleistocene extinction record tells us why. Within a relatively short time after modern humans expanded into Europe and Asia, the megafauna, massive Ice Age animals like woolly mammoths, cave bears, and saber-tooth tigers, began disappearing. These apex predators had dominated their ecosystems for hundreds of thousands of years, but their inflexible diets put them in direct competition with the newest arrivals for the same animal prey. Some became food themselves; others simply couldn't adapt fast enough and died out.

What made modern humans so devastatingly effective? By fundamentally reordering the food chain through their partnership with dogs, together they achieved what neither could have on their own—they claimed the top predator spot. Humans brought strategic thinking, tool use, and endurance. Dogs contributed superior senses, speed, and pack-hunting instincts. Together, they created a survival machine so efficient that the Pleistocene world would never be the same.

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13.4: The Future of Humanity

The Long Now Foundation

YouTube Video

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Public Record. (2016, January 3). *The Clock of the Long Now.* [Video]. YouTube. https://youtu.be/w9uM6BBKfO8?si=WDXEtbEMfNmFv8yp

> "Human existence is about to get much better, much worse, or both." —Robby Berman, American journalist, author, and "fixer"
>
> "As long as you have a ridiculously long view of things, things are getting better." —Robert Sapolsky, Stanford University Primatologist
>
> "I am not here for myself, rather for the future, all the kids that will come." —Nemonte Nenquimo, president of the Waorani Council of Pastaza
>
> "Every individual matters. Every individual has a role to play. Every individual makes a difference."— Jane Goodall, British primatologist
>
> "All flourishing is mutual." – Robin Wall Kimmerer, Potawatomi botanist and author

In this section we'll consider the future of humans. We ask the question, in light of genetic editing and other technological advances, who and what will be considered a person in the future.



Figure 13.4.1: Human Cyborg. Image by Nicky from Pixabay

The Idea of a Human

Through biological anthropology, we've explored what it means to be human—how we are different from and similar to other species. We have considered whether other species have language, or whether it is uniquely human. We have looked at how categories like "race" have been used to justify treating people like sub-humans or non-humans. We have examined non-human primates and their similarities and differences to humans. We have looked at the ambiguity of "humanness" in the paleoanthropological record, asking whether Neanderthals and other hominins were human, and if so, why.

But the very definition of what it means to be human is changing. Historian Michael Bess explains: "...what we're on the verge of doing with bioengineering technologies like **CRISPR** is going to be so qualitatively different and more powerful that I think it's going to force us to reassess who we are and what it means to be human" (Illing 2018).

Taking the Long View

In our busy and complicated lives, we often take the short view, thinking about next week, or, if we're really organized, we might have a five-year plan. The next generation or the next 100 or 1,000 years is typically not foremost in our minds. Thinking ahead, however, is essential for our own personal success and for the future of our planet. The value of looking ahead is captured in the much-cited Iroquois principle of "seven-generation thinking" where one considers the effect of one's actions on generations living 140 or so years from now and acts accordingly. We are connected to the people of the past and are living in a world affected by their decisions and actions. The Long Now Foundation was created in order to promote long-term thinking on the scale of centuries and a sense of long-term responsibility. The Clock of the Long Now, designed to last 10,000 years and chime every century, exemplifies this extreme long view. In this section, we take the long view, and consider the future of humans and our lasting impacts on the planet.

Hacking Humans

In this age of genetic research, we are on the threshold of something entirely new—directly adjusting the human genome and the molecule of life itself—DNA. Gene editing has improved in recent years with a method called CRISPR/Cas-9. This technique delivers gene-editing components which target a section of DNA and snips out any mutations which are then replaced with the desired genetic material. Potentially, the method could be used to edit DNA to prevent diseases like sickle cell anemia or cystic fibrosis which are caused by a single nucleotide polymorphism, or SNP—a change to a single nucleotide base in DNA (Saey 2017). Currently, the Food and Drug Administration (FDA) is barred from clinical trials of editing embryos and the National Institutes of Health cannot fund such research. Scientists have used the technique to edit genes in a human embryo to repair a genetic mutation, but the embryos were not permitted to develop (Howard 2017). One fear is that editing embryos—human genetic engineering—runs the risk of designer babies or "CRISPR babies" that are smarter, prettier, or more athletic, essentially a "genetic elite"—a theme imagined in the 1997 Sci-Fi movie, GATTACA.

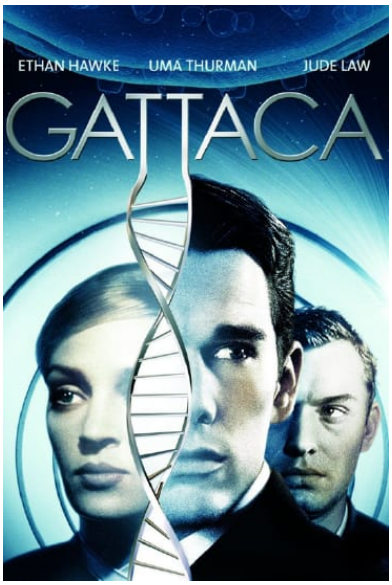


Figure 13.4.2: Movie Poster for 1997 Columbia Pictures Film, GATTACA.

China has already begun using CRISPR on terminal cancer patients. American trials are awaiting approval from the FDA. The head of those trials, Carl June, thinks of the CRISPR trials and research as a kind of biomedical **Sputnik**, spurring technological competition between the U.S. and China. A second concern is how CRISPR will be regulated. Who will have access to it? Will dome be able to profit from it? The United States military is funding genetic research into gene editing, causing alarm over potential military uses (Nelson 2017).

CRISPR has implications beyond humans as well. It is theoretically possible for instance to wipe out mosquitoes that carry malaria or other disease-carrying vermin. Biochemist, Nobel Prize winner, and CRISPR co-creator Jennifer Doudna (2017) discusses the potential dangers of releasing edited animals into the wild, including upsetting the balance of an ecosystem or unintentionally wiping out a species. There is also the advancing field of "de-extinction" or resurrection biology—bringing back some version of extinct species using CRISPR. Doudna points that traits are created by the interaction of many genes, not to mention environmental conditions so it's not clear whether de-extinction could be a reality. Ethical and ecological questions would also have to be addressed in light of de-extinction.

Perhaps most disturbing is the threat of "super-bugs" that are engineered to cause a global pandemic (Bresler and Bakerlee 2018). Using gene-editing to produce artificial SNPs bypasses the process of natural selection. While many of today's diseases are typically zoonotic—transmitted from animals to humans (and vice versa)—gene-editing tools like CRISPR could bypass the process of diseases leaping from one organism to another by targeting a specific one instead by design. Whether caused by accidental release or intentional terrorism, the results of engineered pandemics are equally terrifying. With the threat of weaponized super-bugs, there is a call for creating infrastructure to develop vaccines to keep apace of the bio-hacked super-bug threat, which, with the added processing power of artificial intelligence, could easily and quickly go out of control.

A New Intelligence

In addition to bio-hacking changing the human landscape, other kinds of technology like artificial intelligence (AI) are blurring the lines between computers and human minds. Computers are outpacing humans at tasks that were once considered the exclusive domain of the human brain. The IBM computer Deep Blue beat Grandmaster Garry Kasparov at chess, and it 2016 AlphaGo beat the best in the world at the complex game of Go (Koch 2016). More recently, AI has demonstrated superior performance to humans in standardized tests of creative potential, a domain once thought to be uniquely human (Science Daily 2024). Language model agents have even outperformed humans in programming tasks under time constraints, and AI has shown the ability to outperform human CEOs in strategic decision-making excelling particularly in data-driven tasks like product design and market optimization (AI Index Report 2025, Mudassir, et.al 2024).

In yet another major advancement, Google's Deep Mind AI model called AlphaFold predicted the structures of over 214 million proteins, an achievement that earned a 2024 Nobel Prize in Chemistry and solving a problem that had challenged scientists for decades, accelerating biological research in ways that likely would have taken humans centuries. By cracking the code of protein structures, researchers can potentially design proteins that would benefit humankind including proteins that can be used

as pharmaceuticals, vaccines, nanomaterials, and tiny sensors, as well us helping us to better understand antibiotic resistance (Nobel Prize Press Release 2024; Varadi et. al. 2024)

AlphaGo and these newer systems continuously play or train themselves, steadily improving their skills through a process called "machine learning." Learning, of course, is foundational to human and other animal culture and involves communication and cooperation between individuals. As different AIs eventually learn to "speak" to each other, Philosopher Nick Bostrom suggests that there is the potential for artificial intelligence to exceed that of humans, in what he calls "super-intelligence." Bostrom says, "Think about it. Machine intelligence is the last invention that humanity will ever need to make. The machines will then be better at inventing than we are" (Bostrom 2015).

Nick Bostrom compares the potential of artificial intelligence and humans to the very different pathways of humans and gorillas. One primate is on the verge of extinction, while the other has become a dominant species responsible for that annihilation (Khatchadourian 2017). What will happen to humans in the face of increasingly sophisticated artificial intelligence? The future, he suggests, would be shaped by the preferences of this AI, and consequently we need to consider how to ensure that super-intelligence is aligned with human values. Who gets to decide what those values are?

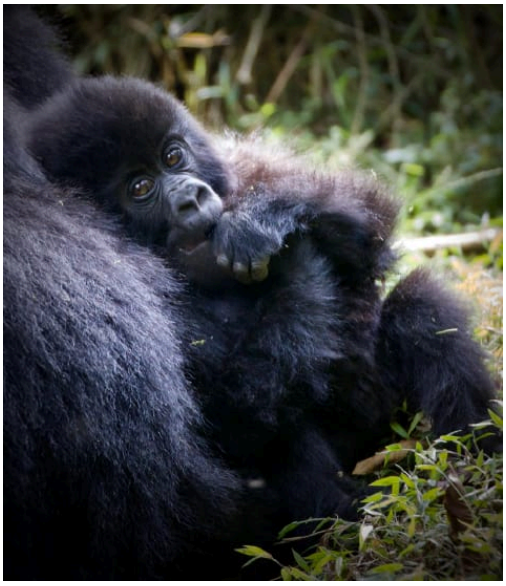


Figure 13.4.3: Baby mountain gorilla. Image by Jeffrey Strain from Pixabay

Thankfully, many great minds and organizations, such as the Center for Humane Technology, are doing the important and urgent work of educating the public and our lawmakers about the need for caution and an evolutionary perspective before deploying AI tools at a mass and unregulated scale, to ensure that they work for the betterment of humanity and human society.

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

TED. (2025, May 1). *Why AI is Our Ultimate Test and Greatest Invitation | Tristan Harris |TED*. [Video]. YouTube. https://youtu.be/6kPHnl-RsVI?si=2gYDpmk29IS_mA8P

The Anthropocene

Other changes are taking place as a result of human intelligence and cooperation, like the rise of cities, massive dams,

huge mining operations, irrigated farms, ocean acidification, surface temperature increases, ocean dead zones, deforestation, atmospheric conditions, and ozone depletion. Ice cores from Antarctica indicate higher levels of greenhouse gases today than in the last 500,000 years. If we reach an increase of 4 degrees Celsius, the use of the planet will change dramatically resulting in extinctions, crop failures, starvation, and huge migrations of people attempting to flee from climate disasters. This has many scientists, and many indigenous communities and elders worrying about the human impact on the earth's systems.

Humans have become the most important agent of ecological and climatological change (Harari 2018). We may be a speck in the galactic sense, but we have transformed our little speck of the universe. Geologists divide time into epochs based on changes in rock layers, called strata, that correspond to changes in climate and environment. Technically speaking, we are currently living in the **Holocene**. Yet observing how we have transformed our planet, scientists are now proposing that we are living in a new age called the **Anthropocene—**the age of humans. Never before has a single species been responsible for altering its ecosystem on such a massive scale. We have become a geophysical force on par with volcanoes and asteroid impacts.

Geologists use fossils and chemical signatures to identify different geological periods. What might be the signs that future geologists will use to define the Anthropocene—the future fossils? Three contenders include fossilized chicken bones, increased radiation levels, and possibly plastics. The Working Group on the Anthropocene has been debating which signatures will likely prevail. This is a difficult prospect since our lifetimes are so miniscule compared to geologic time. The start date of the Anthropocene is also being debated. Some suggest European contact with the Americas and the resulting exchange of agricultural products and death of an estimated 50 million people from disease should mark the official start. Others think the beginning of the Industrial Revolution at 1710 is more appropriate. Still other think 1950 is a solid starting date with the onset of nuclear testing, increased use of plastics, fertilizers, and concrete, along with deforestation, risking carbon dioxide emissions, and increases in domesticated animals like chickens. Wherever you place the starting point, it is clear that humans have had an outsized impact on the planet.

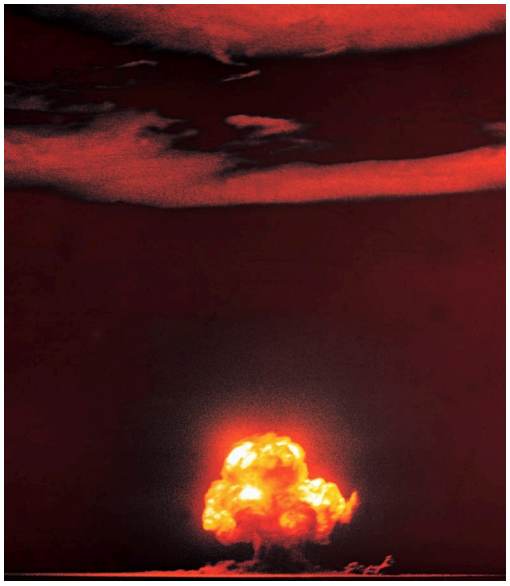


Figure 13.4.4*a*: Sign of the Anthropocene: Trinity test site explosion. Image by Jack W. Aeby, July 16, 1945, Civilian worker at Los Alamos laboratory, working under the aegis of the Manhattan Project., Public domain, via Wikimedia Commons



Figure 13.4.4*b*: Sign of the Anthropocene: "Broiler" chickens raised for slaughter. Image by Farm Sanctuary under CC BY-NC-ND 2.0 via Flickr



Figure 13.4.4*c*: Sign of the Anthropocene:Marine litter. Image by Bo Eide under CC BY-NC-ND 2.0 via Flickr

Making New Stories: What Kind of Ancestors Will We Be?

We have looked at how humans are "swimming" in culture. Our own culture can be heard to see because we take it for granted or assume it is normal. Some of our most salient realities are created by people—everything from money to laws to some of our most cherished values. Even those who are not religious very often have deep-seated values that are sacred to them. Those values are in turn backed up by symbols and stories.

Nonetheless, our shared web of meaning, our sacred values and the symbols and stories that accompany them, can change in an instant. Previously illegal drugs like marijuana can suddenly become legal. Our nation's long standing practice of the peaceful transfer of power from one presidential administration to the next can be disrupted through violence on the U.S. Capitol—an attack not just on the building, but on democracy itself. Even the ideals and values of our parents can seem quaint to us. With technology changing so fast, people worry that our values system cannot keep pace with the changes.

Historian Michael Bess cautions, "We need to sit down with ourselves and say,

> 'As I look at my daily life, as I look at the past year, as I look at the past five years, what are the aspects of my life that have been the most rewarding and enriching? When have I been happiest? What are the things that have made me flourish?'

If we ask these questions in a thoughtful, explicit way, then we can say more definitely what these technologies are adding to the human experience and, more importantly, what they're subtracting from the human experience (Illing 2018). As we experience new changes in technology and what it mean to be human, people, especially young people, have much power in deciding the shape of a culture's values and the stories and symbols that support those values. The actions of your generation will shape the course of the future as we enter the Anthropocene. If we do this with eyes both on the past, our ancient story, as well as on the future, towards a new story, we stand to make better choices for our species and all beings who call this planet home.

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13.5: Key Terms

Anthropocene – Geological epoch known as the “Age of Humans.” Scientists propose this as a replacement to the current Holocene Epoch to mark the impact of human driven transformation of the earth.

Atlatl - A prehistoric tool used for launching projectiles (usually spears) at higher velocities than they would otherwise travel when thrown by hand.

Cortex - The outside, or rough outer covering, of a rock. Usually the cortex is removed during the process of stone tool creation.

Ethnocentric – Applying negative judgments to other cultures based on comparison to one’s own.

Flexed position – Fetal position, in which the legs are drawn up to the middle of the body and the arms are drawn toward the body center. Intentional burials are often found in the flexed body position.

Grave goods – Items included with a body at burial. Items may signify occupation or hobbies, social status, or level of importance in the community, or they may be items believed necessary for the afterlife.

Haft – A handle. Also used as a verb---to attach a handle to an item, such as a stone tool.

Holocene – The current geological epoch, starting approximately 11,000 years ago after the last ice age ended.

Hunter-gatherers - People who live off wild, non-domesticated food; also called foragers

Infraorbital foramina – Small holes on the maxilla bone of the face that allows nerves and blood to reach the skin.

KYA - abbreviation for thousands of years ago

Levallois technique – A distinctive technique of stone tool manufacturing used by Archaic *Homo sapiens*, including Neanderthals. The technique involves the preparation of a core and striking edges off in a regular fashion around the core. Then a series of similarly sized pieces can be removed, which can then be turned into different tools.

Midfacial prognathism – A forward projection of the nose or the middle facial region. Usually associated with Neanderthals.

Mousterian tools – The stone tool industry of Neanderthals and their contemporaries in Africa and Western Asia. Mousterian tools are known for a diverse set of flake tools, which is different from the large bifacial tools of the Acheulean industry.

MYA - abbreviation for millions of years ago

Nasal aperture – The opening for the nose visible on a skull. Often pear- or heart-shaped.

Occipital bun – A prominent bulge or projection on the back of the skull, specifically the occipital bone. This is a feature present only on Neanderthal skulls.

Ochre – A natural clay pigment mixed with ferric oxide and sand. Ranges in color from brown to red to orange.

Phylogenetic – Relating to the evolutionary development and diversification of a species or group of organisms.

Retromolar gap – A space behind the last molar and the end of the jaw. This is a feature present only on Neanderthals. It also occurs through cultural modification in modern humans who have had their third molars, or wisdom teeth, removed.

Sputnik – Refers to the Sputnik 1 satellite, the first Earth satellite launched into space by the Soviet Union in 1957. This event marked the beginning of the Space Age and the Space Race between the U.S. and the Soviet Union which led to the creation of NASA.

Supernatural - Powers or phenomena not subject to the laws of nature.

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13.6: References and Attributions

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