Evolution

IF3211 Domain Specific Computation

School of Electrical Engineering and Informatics ITB

Content

- Descent with Modification
- The Origin of Life
- Early Life and the Diversification of Prokaryotes
- Tools

Descent with Modification

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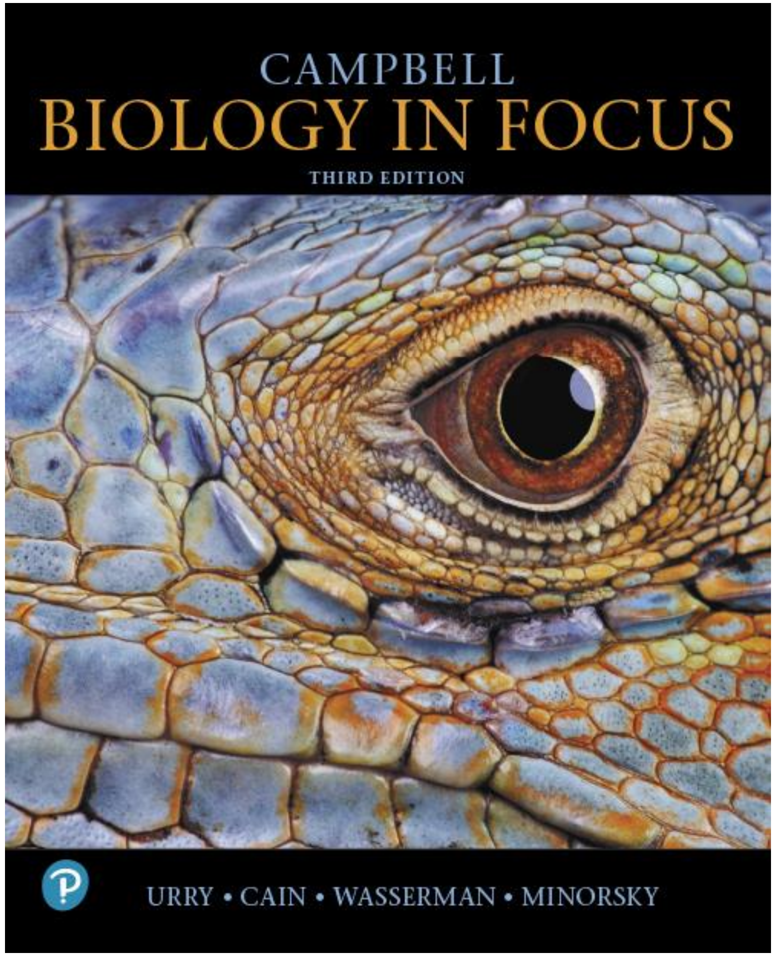


Chapter 19

Descent with Modification

Lecture Presentations by
Kathleen Fitzpatrick and Nicole Tunbridge,
Simon Fraser University

Overview: Endless Forms Most Beautiful (1 of 4)

- Lepidopteran insects (moths and butterflies) have many features in common, including a juvenile feeding stage called a caterpillar
- Lepidopteran species also have many features that are distinct from each other in both the caterpillar and adult forms
  - For example, the adult dead-leaf moth mimics a dead leaf, and the caterpillar mimics a snake about to strike

https://sciencenotes.org/what-is-the-difference-between-a-butterfly-and-a-moth/

Overview: Endless Forms Most Beautiful (2 of 4)

- Lepidopterans illustrate three key observations about life
  - The fit between organisms and their environment
  - The shared characteristics (unity) of life
  - The diversity of life

Overview: Endless Forms Most Beautiful (3 of 4)

- A new era of biology began in 1859 when Charles Darwin published *On the Origin of Species*
- *On the Origin of Species* focused biologists' attention on the great diversity of organisms

Overview: Endless Forms Most Beautiful (4 of 4)

- Darwin noted that current species are descendants of ancestral species
- **Evolution** can be defined by Darwin’s phrase **descent with modification**
- Evolution can be viewed as both a pattern and a process

Concept 19.1: The Darwinian Revolution Challenged Traditional Views of a Young Earth Inhabited by Unchanging Species

- Darwin developed his proposal over time, influenced by the work of others and the unique species he observed in his travels
- His revolutionary ideas had deep historical roots

Scala Naturae and Classification of Species (1 of 3)

- The Greek philosopher Aristotle (384–322 BCE) viewed species as fixed and arranged them on a scale of increasing complexity, or **scala naturae**
- Each form of life was considered perfect and permanent, consistent with the Old Testament

Scala Naturae and Classification of Species (2 of 3)

- Carolus Linnaeus, the founder of modern taxonomy, adopted a nested classification system, grouping species into increasingly general categories
- He also developed the binomial format for naming species (such as *Homo sapiens* for humans)

Scala Naturae and Classification of Species (3 of 3)

- Linnaeus ascribed resemblance among species to the pattern of creation rather than evolution
- A century later, Darwin later argued that evolutionary relationships should be the basis for classification

Concept 19.2: Descent with Modification by Natural Selection Explains the Adaptations of Organisms and the Unity and Diversity of Life

- Some doubt about the permanence of species preceded Darwin's ideas

Darwin's Research

- Charles Darwin (1809–1882) grew up with a consuming interest in nature
- He first studied medicine (unsuccessfully) and then theology at Cambridge University
- After graduation, he took a position as naturalist for a five-year, around-the-world voyage on the HMS *Beagle*

The Voyage of the *Beagle* (1 of 3)

- Darwin observed and collected thousands of plants and animals on his travels
- He described features that suited organisms to their environments
- He observed that fossils resembled living species from the same region, and living species resembled other species from nearby regions

Figure 19.5

The Voyage of HMS *Beagle* (December 1831–October 1836)

Ideas from *The Origin of Species*

- Descent with modification by natural selection explains three broad observations about nature
  - The unity of life
  - The diversity of life
  - The ways that organisms are suited for life in their environments

Descent with Modification (1 of 2)

- Darwin used the phrase **descent with modification** in *The Origin of Species* to summarize his perception of the unity and diversity of life
- He thought of evolution as descent (shared ancestry, resulting in shared characteristics) and modification (accumulation of differences)

Descent with Modification (2 of 2)

- Darwin viewed the history of life like a tree with a common trunk representing shared ancestry and branches representing diversity among species
  - Tips of branches represent present-day organisms
  - Unlabeled branches represent extinct groups
  - Each fork represents the most recent common ancestor of the lines that branch from that point
- Fossils of extinct species help to “fill in” the morphological gaps between present-day groups

Figure 19.8

“I Think …”

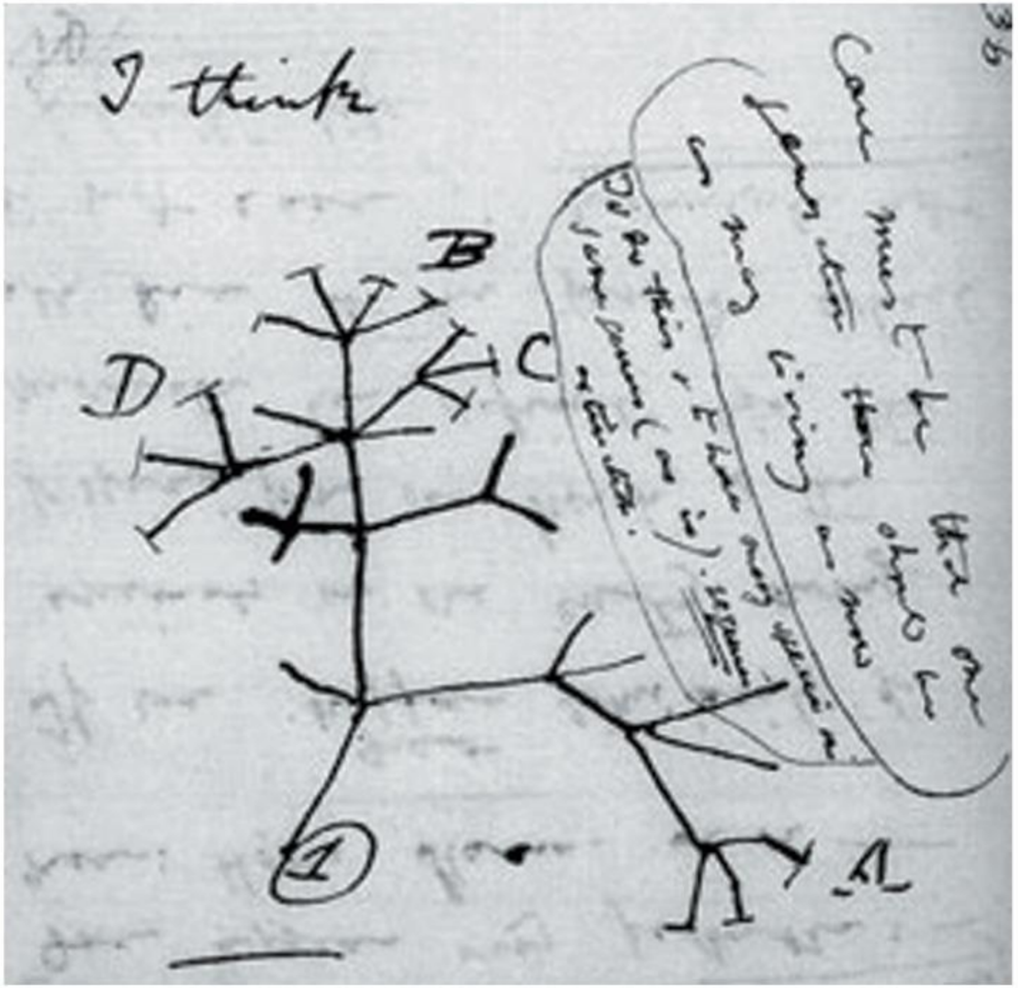
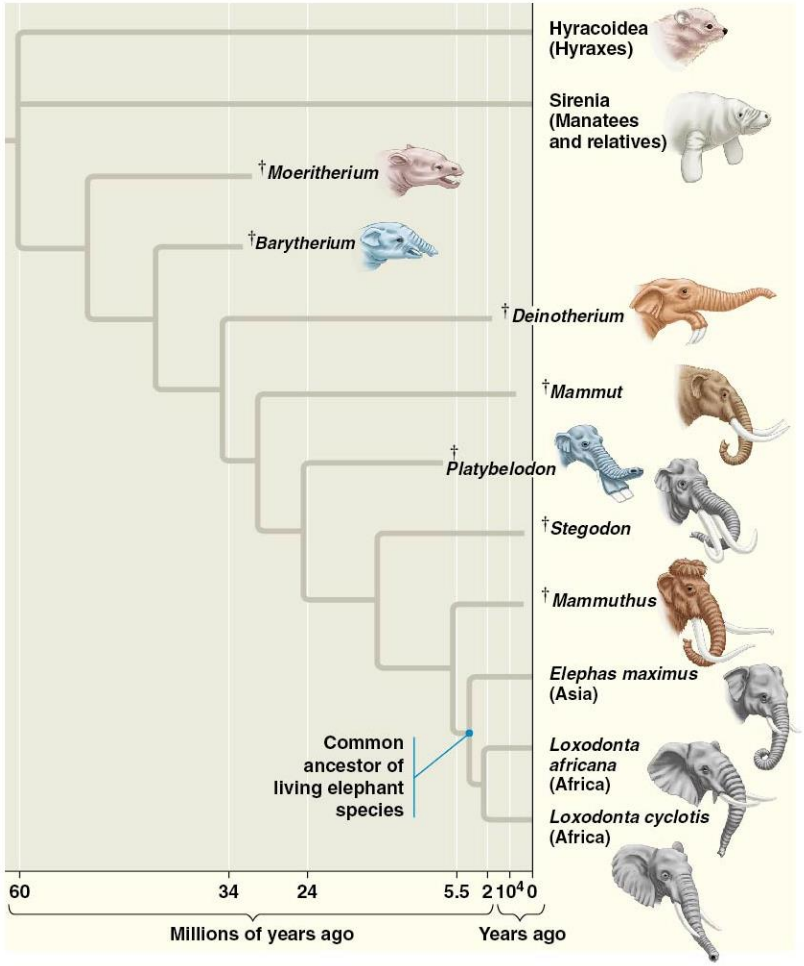


Figure 19.9

Descent with Modification

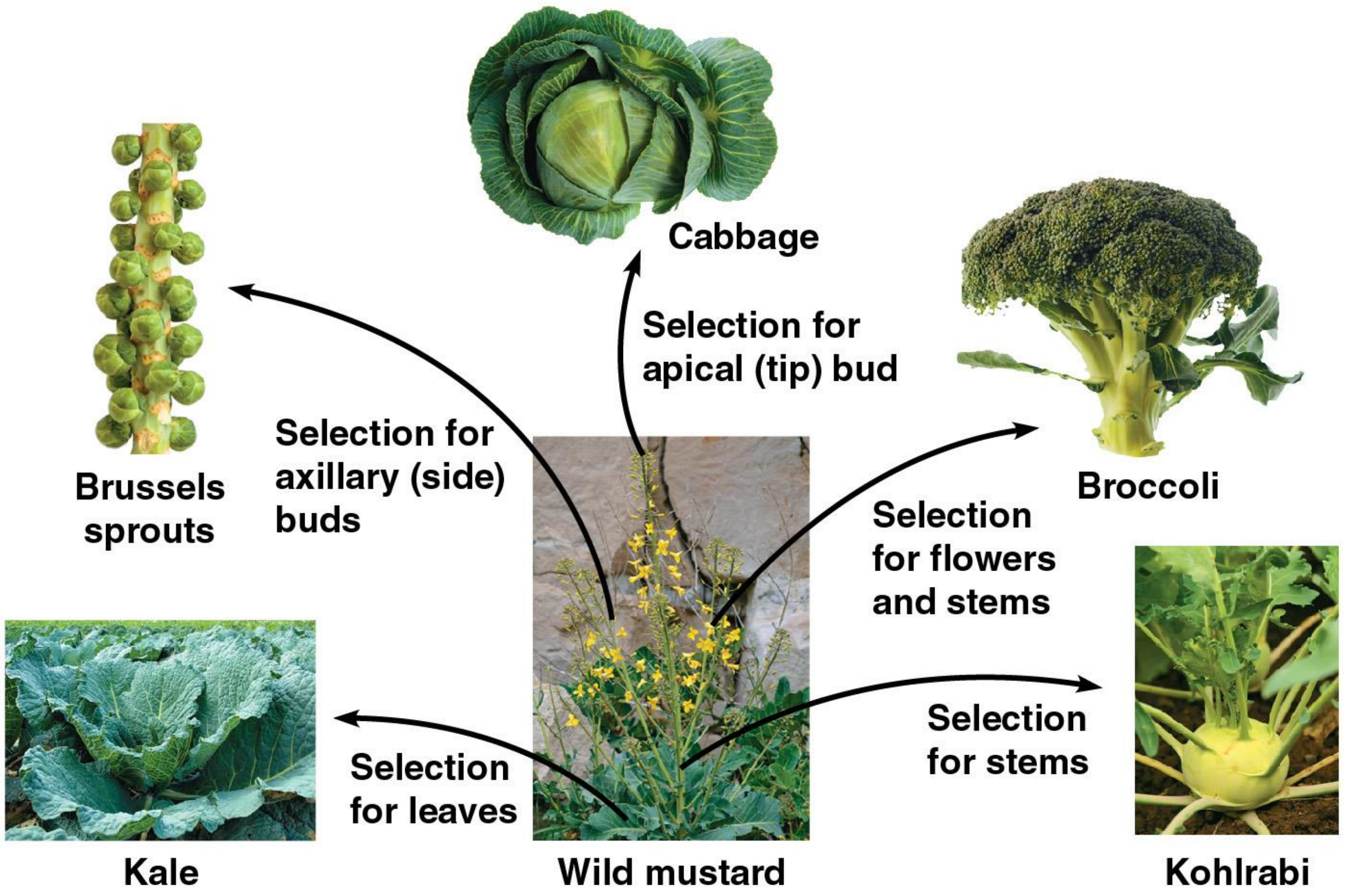


Artificial Selection, Natural Selection, and Adaptation (1 of 8)

- Humans modify other species over generations through selective breeding of individuals with desired traits, a process called **artificial selection**
- Darwin argued that a similar process occurs in nature

Figure 19.10

Artificial Selection



Artificial Selection, Natural Selection, and Adaptation (2 of 8)

- Darwin drew two inferences from two observations
- **Observation #1**: Members of a population often vary in their inherited traits

Figure 19.11

Variation in a Population

Artificial Selection, Natural Selection, and Adaptation (3 of 8)

- **Observation #2:** All species can produce more offspring than the environment can support; many of these offspring fail to survive and reproduce

Key Features of Natural Selection (1 of 2)

- Individuals with certain heritable traits survive and reproduce at a higher rate than other individuals
- Over time, natural selection increases the frequency of adaptations that are favorable in a given environment
- If an environment changes, natural selection may result in adaptation to the new conditions, sometimes giving rise to new species

Figure 19.13

Camouflage as an Example of Evolutionary Adaptation

Key Features of Natural Selection
(2 of 2)

- Populations, **not individuals**, evolve over time
- Natural selection can only increase or decrease heritable traits that differ among individuals in a population
- The specific traits that are adaptive will vary from place to place and over time

The Origin of Species

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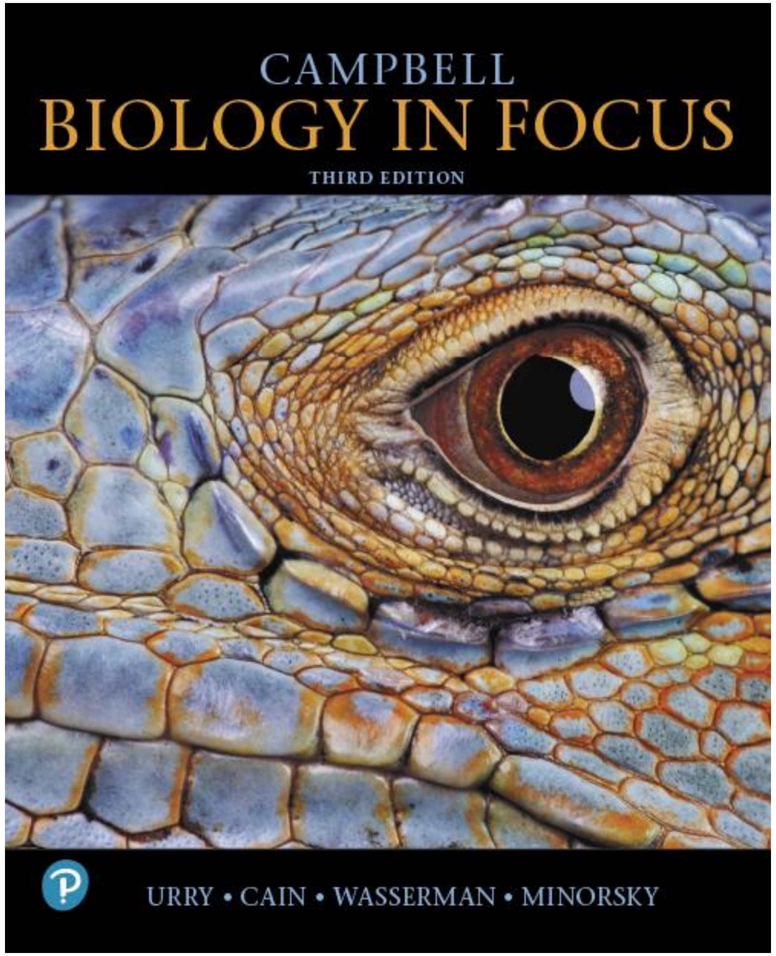


Chapter 22

The Origin of Species

Lecture Presentations by
Kathleen Fitzpatrick and Nicole Tunbridge,
Simon Fraser University

Pearson

Overview: That “Mystery of Mysteries” (1 of 3)

- In the Galápagos Islands Darwin discovered plants and animals found nowhere else on Earth

Figure 22.1

How Did This Flightless Bird Come to Live on the Isolated Galápagos Islands?

Figure: Galapágos Giant Tortoise

▲ Galápagos giant tortoise, another species unique to the islands

Overview: That "Mystery of Mysteries" (2 of 3)

- **Speciation** is the process by which one species splits into two or more species
- When one species splits into two, the species that result share many characteristics inherited from their common ancestor

Overview: That "Mystery of Mysteries" (3 of 3)

- Speciation forms a conceptual bridge between microevolution and macroevolution
- **Microevolution** consists of changes in allele frequency in a population over time
- **Macroevolution** refers to broad patterns of evolutionary change above the species level
  - For example, the origin of new groups of organisms, such as mammals, from a series of speciation events

Concept 22.1: The Biological Species Concept Emphasizes Reproductive Isolation

- Species is a Latin word meaning “kind” or “appearance”
- Biologists compare morphology, physiology, biochemistry, and DNA sequences when grouping organisms

The Biological Species Concept

- The **biological species concept** states that
  - A **species** is a group of populations whose members have the potential to interbreed in nature and produce viable, fertile offspring; they do not breed successfully with other such groups
- Gene flow between populations holds the gene pool of a species together

Reproductive Isolation (3 of 11)

- **Habitat isolation:** Two species encounter each other rarely, or not at all, because they occupy different habitats, even though not isolated by physical barriers

Limitations of the Biological Species Concept

- The biological species concept cannot be applied to fossils or asexual organisms
- The biological species concept emphasizes absence of gene flow, but gene flow does sometimes occur between distinct species
  - For example, grizzly bears and polar bears can mate, producing “grolar bears”

Figure 22.4

Hybridization Between Two Species of Bears in the Genus *Ursus*

◀ **Grizzly bear (*U. arctos*)**

▼ **Polar bear (*U. maritimus*)**

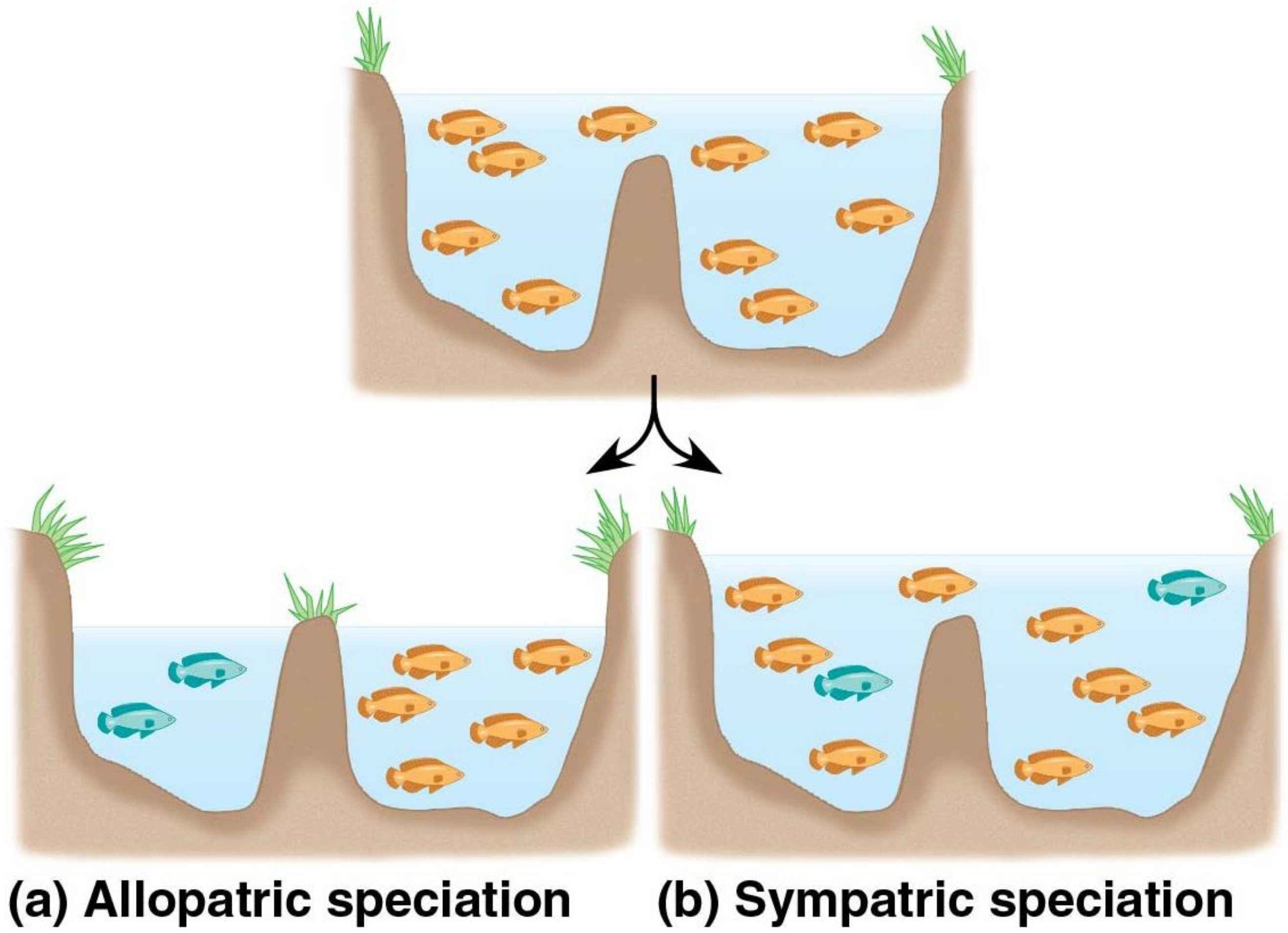
◀ **Hybrid “grolar bear”**

Concept 22.2: Speciation Can Take Place with or Without Geographic Separation

- Speciation can occur in two ways
  - Allopatric speciation occurs when populations are geographically isolated from each other
  - Sympatric speciation occurs when populations are not geographically isolated

Figure 22.5

The Geography of Speciation

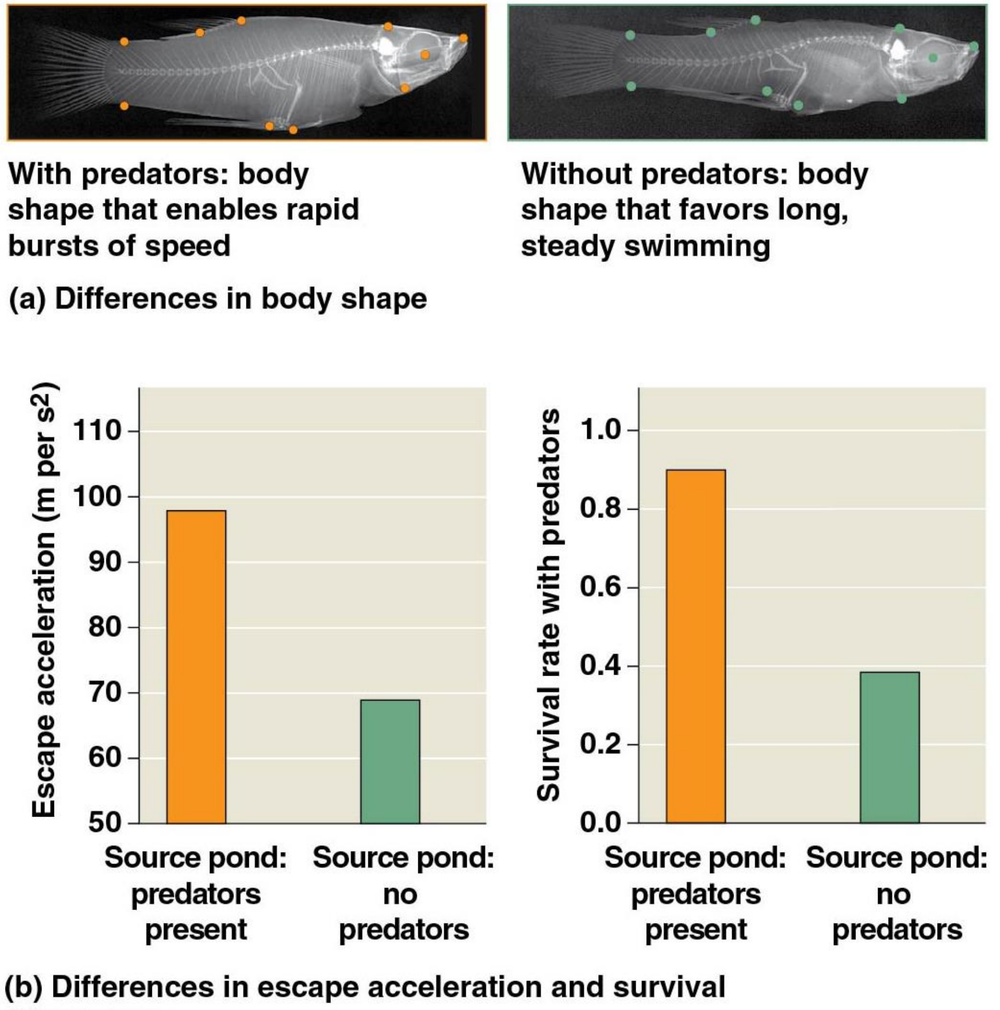


Allopatric ("Other Country") Speciation

- In **allopatric speciation**, gene flow is interrupted when a population is divided into geographically isolated subpopulations
  - For example, the flightless cormorant of the Galápagos likely originated from a flying species on the mainland

Figure 22.6

Evolution in Mosquitofish Populations



The Process of Allopatric Speciation (3 of 3)

- Reproductive isolation may arise as a by-product of genetic divergence
  - For example, behavioral isolation evolved between mosquitofish from ponds with and without predators
  - Female mosquitofish preferred to mate with males that had body shapes more similar to their own

Sympatric (“Same Country”) Speciation

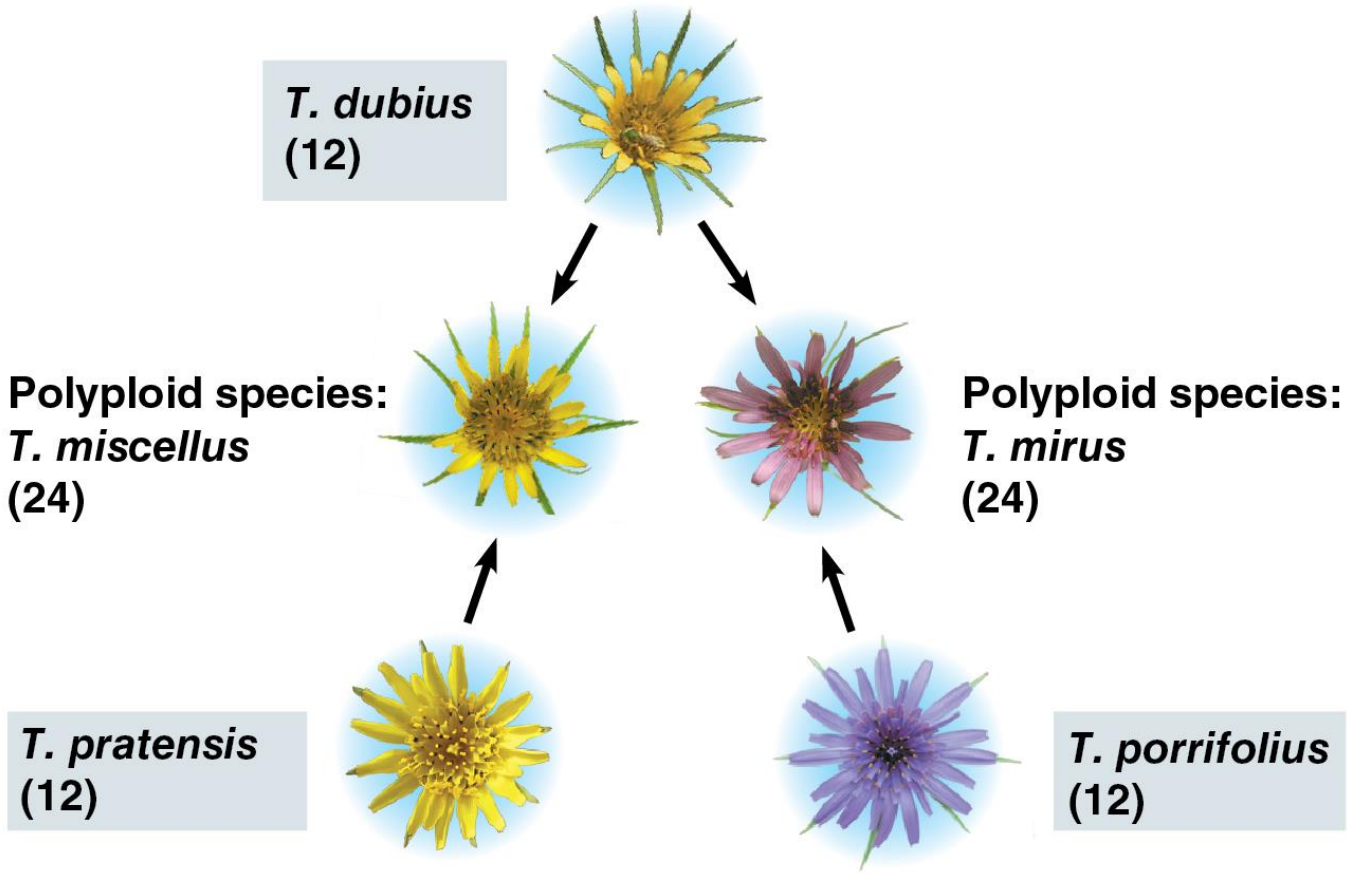
- **Sympatric speciation** takes place in populations that live in the same geographic area
- It occurs when gene flow is reduced through factors including
  - Polyploidy
  - Habitat differentiation
  - Sexual selection

Polyploidy (1 of 5)

- **Polyploidy** is the presence of extra sets of chromosomes due to accidents during cell division
- Polyploidy speciation occasionally occurs in animals but is much more common in plants

Figure 22.11

Allopolyploid Speciation in *Tragopogon*



Concept 22.3: Hybrid Zones Reveal Factors That Cause Reproductive Isolation

- A **hybrid zone** is a region in which members of different species mate and produce hybrids
- Hybrids are the result of mating between species with incomplete reproductive barriers

Hybrid Zones over Time (1 of 4)

- When closely related species meet in a hybrid zone, there are three possible outcomes
  - Reinforcement of barriers
  - Fusion of species
  - Stability

Figure 22.15

Formation of a Hybrid Zone and Possible Outcomes for Hybrids over Time

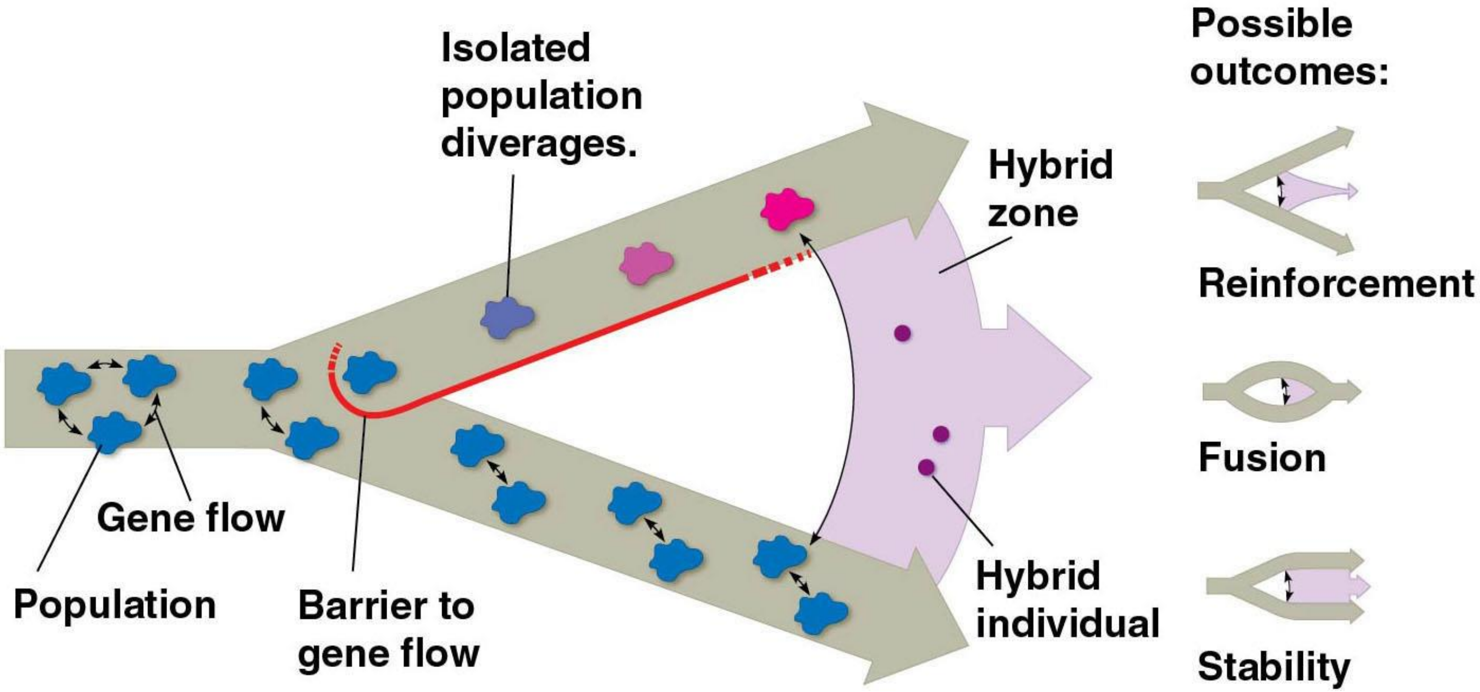
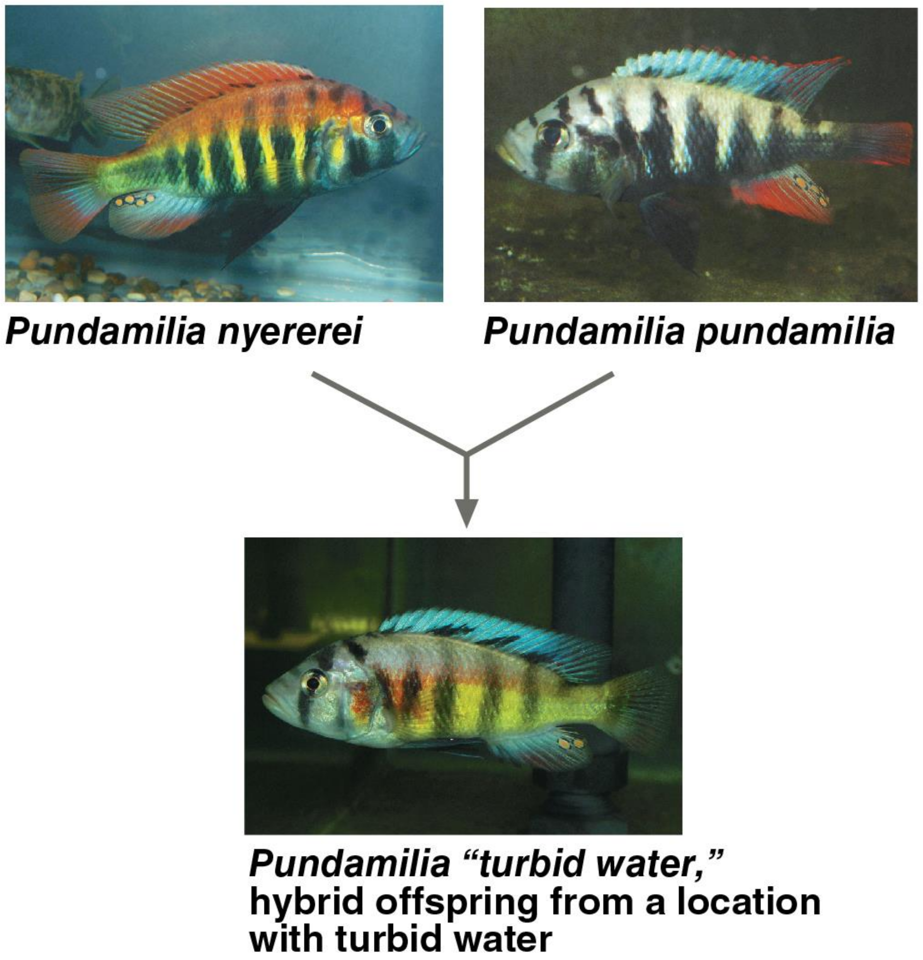


Figure 22.16

Fusion: The Breakdown of Reproductive Barriers



Early Life and the Diversification of Prokaryotes

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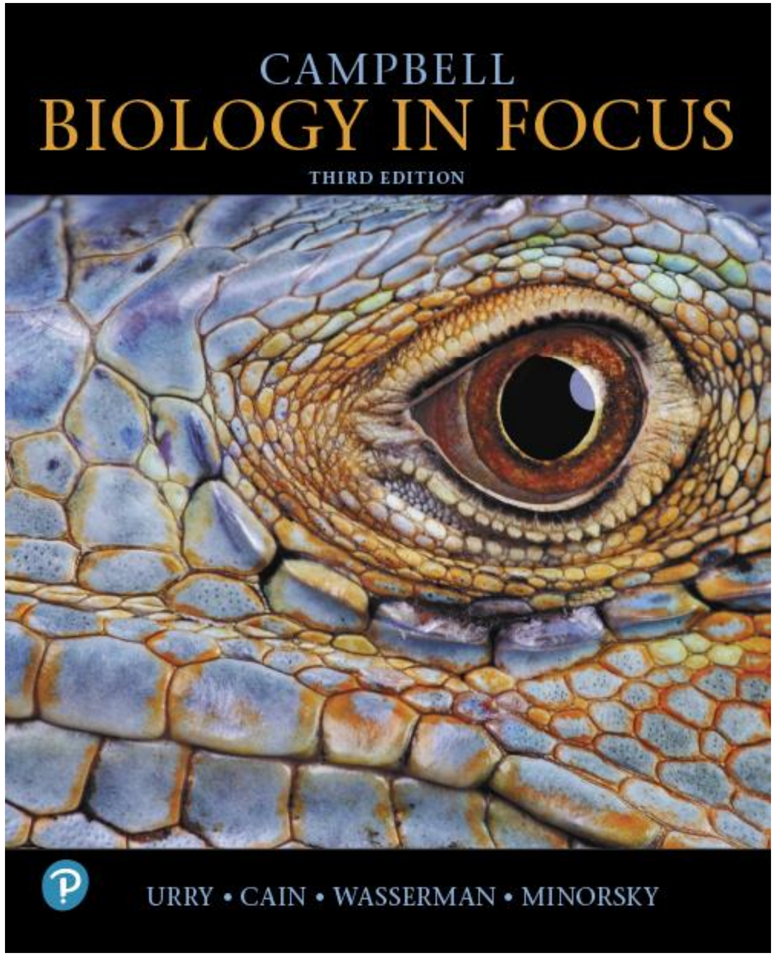

Chapter 24

Early Life and the Diversification of Prokaryotes

Lecture Presentations by
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Overview: The First Cells (1 of 2)

- Earth formed 4.6 billion years ago
- The oldest fossil organisms are **prokaryotes**, dating back to 3.5 billion years ago
- Prokaryotes are single-celled organisms in the domains Bacteria and Archaea
- Some of the earliest prokaryotic cells lived in dense mats; others were free-floating individual cells

Figure 24.1

What Organisms Lived on Early Earth?

Overview: The First Cells (2 of 2)

- Prokaryotes were alone on Earth until the first eukaryotic cells appeared 1.8 billion years ago
- They are the most abundant organisms on Earth
- They thrive in most environments, including places too acidic, salty, cold, or hot for most other organisms
- Some prokaryotes colonize the bodies of other organisms

Concept 24.1: Conditions on Early Earth Made the Origin of Life Possible

- Chemical and physical processes on early Earth may have produced very simple cells through a sequence of four stages

1. Abiotic synthesis of small organic molecules
2. Joining of these small molecules into macromolecules
3. Packaging of molecules into **protocells**, membrane-enclosed droplets that maintain consistent internal chemistry
4. Origin of self-replicating molecules

Synthesis of Organic Compounds on Early Earth (1 of 3)

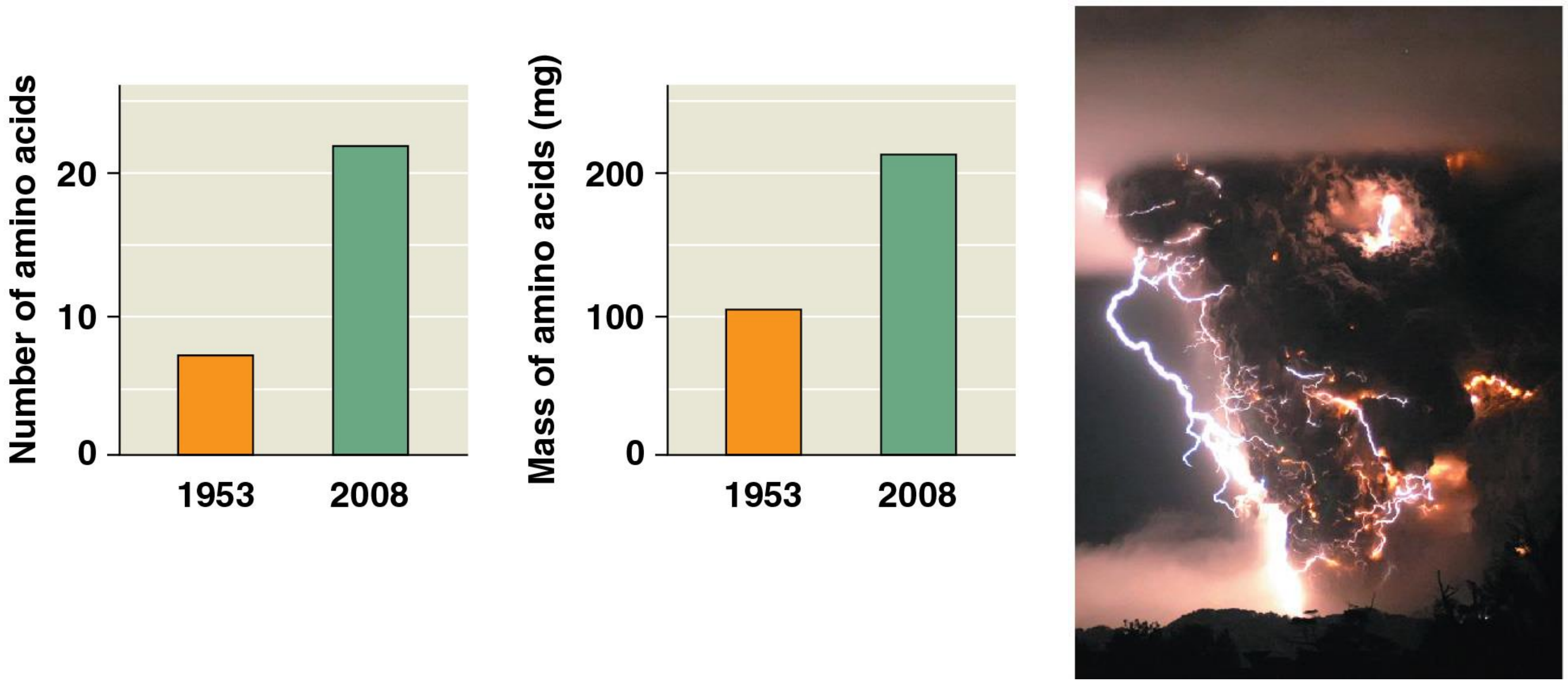
- Earth's early atmosphere had little oxygen and likely contained water vapor and compounds released by volcanic eruptions
  - For example, nitrogen, nitrogen oxides, carbon dioxide, methane, ammonia, and hydrogen
- As Earth cooled, water vapor condensed into oceans, and most hydrogen escaped into space

Synthesis of Organic Compounds on Early Earth (3 of 3)

- However, some evidence suggests that the early atmosphere was neither reducing nor oxidizing
- Recent experiments indicate organic molecules can also be produced in “neutral” atmospheres
- Organic compounds may also have originated in reducing conditions by volcanoes or deep-sea vents
- Amino acids form spontaneously in experimental conditions simulating volcanic eruptions

Figure 24.3

Amino Acid Synthesis in a Simulated Volcanic Eruption



Abiotic Synthesis of Macromolecules

- RNA monomers have been produced spontaneously from simple precursor molecules
- Small organic molecules polymerize when they are concentrated on hot sand, clay, or rock
- Amino acid polymers may have functioned as weak catalysts for chemical reactions on early Earth

Protocells (1 of 2)

- Replication and metabolism are key properties of life that likely appeared together in early protocells
- Protocells may have been fluid-filled vesicles with a membrane-like structure
- In water, lipids and other organic molecules can spontaneously form vesicles with a lipid bilayer

Protocells (2 of 2)

- Montmorillonite, a soft mineral clay, greatly increases the rate of vesicle formation by concentrating organic molecules on its surface
- Abiotically produced vesicles have a semi-permeable membrane and have simple reproduction
- They absorb molecules from the surroundings and metabolize reagents from external sources

Self-Replicating RNA (1 of 4)

- The first genetic material was likely RNA, not DNA
- Single-stranded RNA molecules have three-dimensional shapes, making catalytic function possible
- **Ribozymes** are RNA molecules that can catalyze reactions; some are also self-replicating

Fossil Evidence of Early Life (1 of 3)

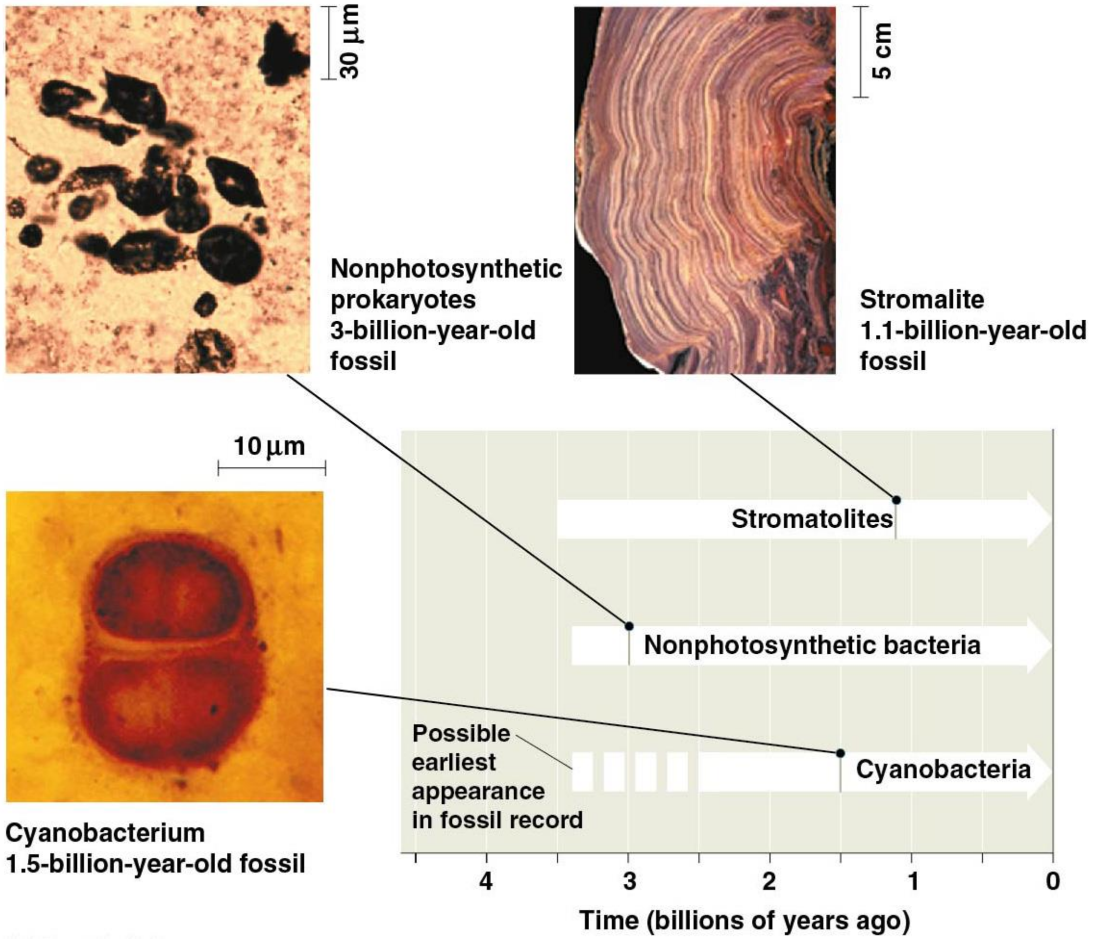
- Many of the oldest fossils are stromatolites, layered rocks that formed from the activities of prokaryotes
- The earliest stromatolites are 3.5 billion years old
- Stromatolites living today are formed by cyanobacteria and other photosynthetic bacteria
- Stromatolites with distinct morphologies and habitats evolved 3.1 and 2.8 billion years ago

Fossil Evidence of Early Life (2 of 3)

- Fossils of individual prokaryotic cells have been found in 3.4-billion-year-old rocks from Australia
- 3.4-billion-year-old fossil cells resembling cyanobacteria were found in South Africa, both individually and within stromatolites
- By 2.5 billion years ago, diverse communities of cyanobacteria populated the oceans

Figure 24.5

Appearance in the Fossil Record of Early Prokaryote Groups

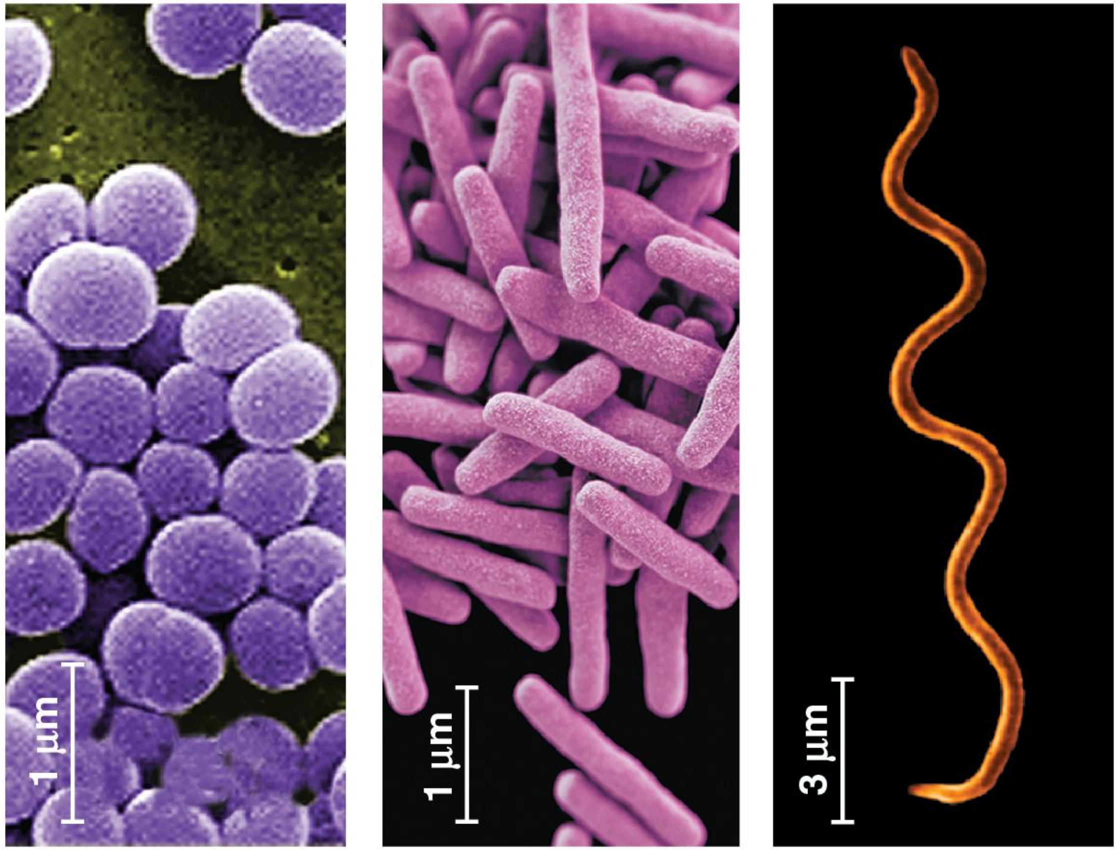


Concept 24.2: Diverse Structural and Metabolic Adaptations Have Evolved in Prokaryotes

- Most prokaryotes are unicellular, although some species form colonies
- Prokaryotic cells typically have much smaller diameters than eukaryotic cells; 0.5–5µm compared to 10–100µm for eukaryotes
- Prokaryotes have a variety of cell shapes, including spheres (cocci), rods (bacilli), and spirals

Figure 24.6

The Most Common Shapes of Prokaryotes



(a) Spherical **(b) Rod-shaped** **(c) Spiral**

Nutritional and Metabolic Adaptations (1 of 2)

- Prokaryotes can be categorized by how they obtain energy and carbon
  - Phototrophs obtain energy from light
  - Chemotrophs obtain energy from organic compounds or inorganic chemicals like H_2S
  - Autotrophs use inorganic carbon sources like CO_2
  - Heterotrophs obtain carbon from organic compounds

Nutritional and Metabolic Adaptations (2 of 2)

- Combining energy and carbon sources results in the four major modes of nutrition
  - **Photoautotroph**
  - **Chemoautotroph**
  - **Photoheterotroph**
  - **Chemoheterotroph**

Table 24.1

Major Nutritional Modes

Mode	Energy Source	Carbon Source	Types of Organisms
AUTOTROPH			
Photoautotroph	Light	CO_2, HCO_3^-, or related compound	Photosynthetic prokaryotes (for example, cyanobacteria); plants; certain protists (for example, algae)
Chemoautotroph	Inorganic chemicals (such as H_2S, NH_3, or Fe^{2+})	CO_2, HCO_3^-, or related compound	Unique to certain prokaryotes (for example, *Sulfolobus*)
HETEROTROPH			
Photoheterotroph	Light	Organic compounds	Unique to certain aquatic and salt-loving prokaryotes (for example, *Rhodobacter*, *Chloroflexus*)
Chemoheterotroph	Organic compounds	Organic compounds	Many prokaryotes (for example, *Clostridium*) and protists; fungi; animals; some plants

The Role of Oxygen in Metabolism

Prokaryotic metabolism varies with respect to O_2

- Obligate aerobes require O_2 for cellular respiration
- Obligate anaerobes are poisoned by O_2 and either use fermentation or **anaerobic respiration** with substances other than O_2 as final electron acceptors
- Facultative anaerobes can use O_2 when present or carry out fermentation or anaerobic respiration

Nitrogen Metabolism

- Nitrogen is essential for the production of amino acids and nucleic acids in all organisms
- Eukaryotes cannot use atmospheric nitrogen N_2
- Some prokaryotes use **nitrogen fixation** to convert atmospheric nitrogen N_2 to ammonia NH_3 that can be used by both prokaryotes and eukaryotes

Adaptations of Prokaryotes: A Summary

- The ongoing success of prokaryotes is primarily the result of physiological and metabolic diversification
- Metabolic diversification of prokaryotes was the first great wave of adaptive radiation in the history of life

Concept 24.3: Rapid Reproduction, Mutation, and Genetic Recombination Promote Genetic Diversity in Prokaryotes

- Prokaryotes have considerable genetic variation
- Three factors contribute to this genetic diversity
    - Rapid reproduction
    - Mutation
    - Genetic recombination

Rapid Reproduction and Mutation

- Prokaryotes reproduce by binary fission; most offspring are genetically identical to the parent cell
- Mutations are rare, but because generation times are short, they accumulate quickly in a population
- High genetic diversity allows for rapid evolution
- Prokaryotes are not "primitive:" they are highly evolved due to rapid adaptation to new conditions

Genetic Recombination

- Genetic recombination, the combining of DNA from two sources, contributes to diversity
- Prokaryotic DNA from different individuals can be brought together by transformation, transduction, and conjugation
- Movement of genes among individuals from different species is called horizontal gene transfer

Prokaryotes in Research and Technology
(1 of 4)

- Experiments using prokaryotes have led to important advances in D N A technology
  - For example, *E. coli* is used in gene cloning, and the D N A polymerase from *Pyrococcus furiosus* is used in the P C R technique

Prokaryotes in Research and Technology
(2 of 4)

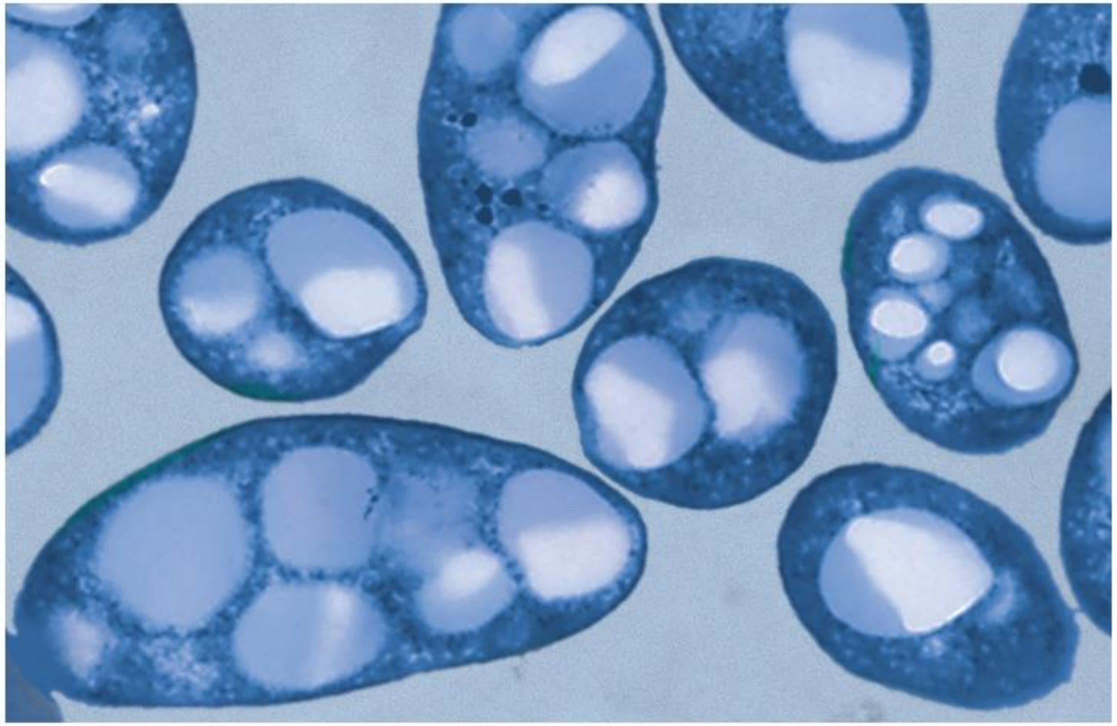
- Experimental treatment of human cells with the prokaryotic C RISPR-Cas9 system has shown promising results for the treatment of HIV

Prokaryotes in Research and Technology (3 of 4)

- Some bacteria can be used to make natural, biodegradable plastics
- Others have been engineered to produce ethanol from plant sources and agricultural and municipal wastes

Figure 24.27

Bacteria Synthesizing and Storing PHA, a Component of Biodegradable Plastics



Prokaryotes in Research and Technology (4 of 4)

- Prokaryotes are also used in **bioremediation**, the use of organisms to remove pollutants from the environment

Figure 24.28

Bioremediation of an Oil Spill

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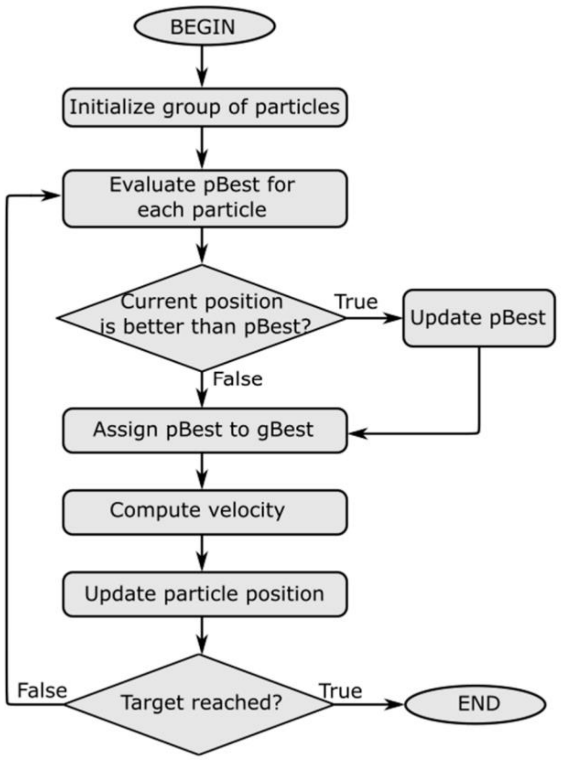
Computing Tools

Several Computing Tasks

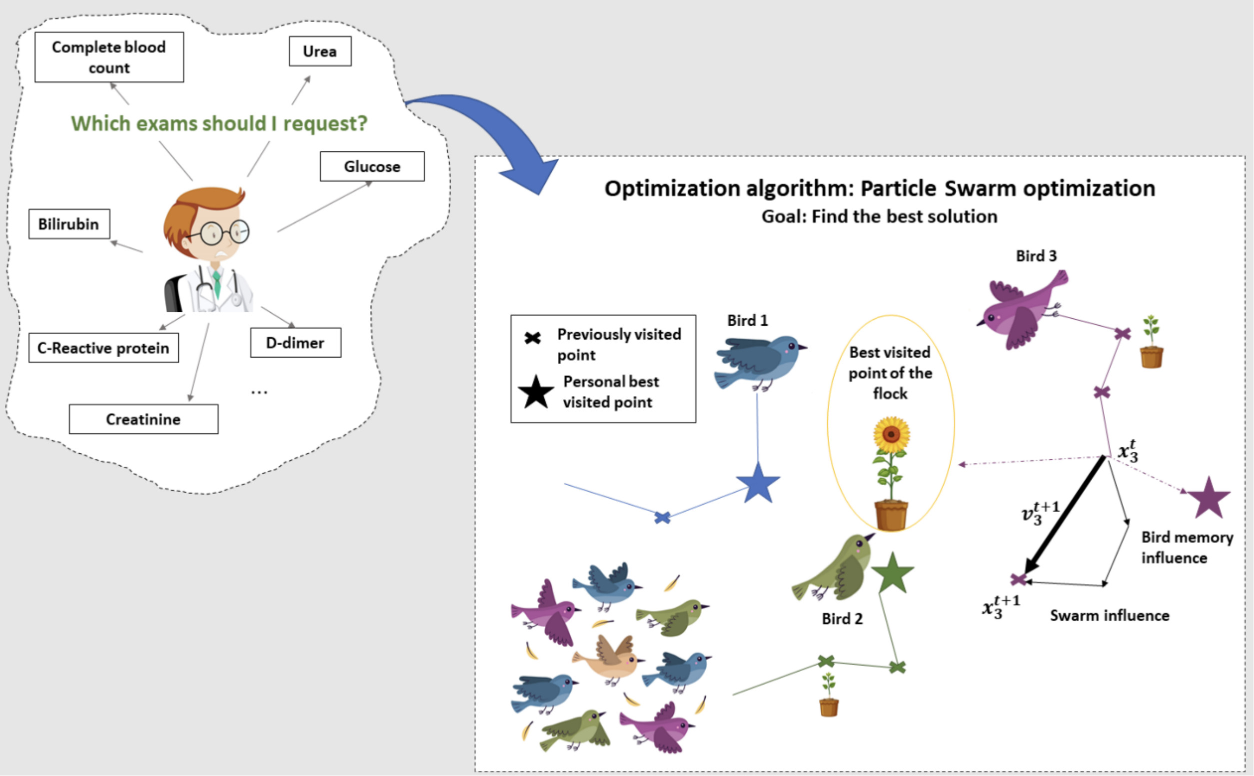
- Phylogeny Tree Reconstruction
- Bio-inspired Algorithms: Particle Swarm Optimization (Evolutionary Algorithm)
- Computational Biology Tools: MEGA, BEAST, etc.

Particle Swarm Optimization



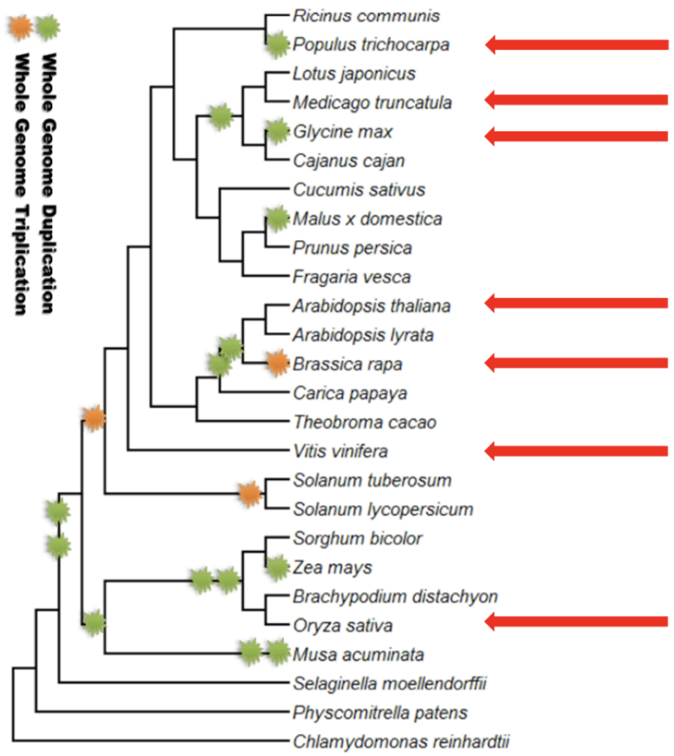
- Particle swarm optimization (PSO): a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality.
- PSO is a powerful meta-heuristic optimization algorithm and inspired by swarm behavior observed in nature such as fish and bird schooling. PSO is a Simulation of a simplified social system. The original intent of PSO algorithm was to graphically simulate the graceful but unpredictable choreography of a bird flock.
- In nature, any of the bird's observable vicinity is limited to some range. However, having more than one birds allows all the birds in a swarm to be aware of the larger surface of a fitness function.

PSO for Optimizing Diagnostic Process



- "Rapid protocols to support Covid-19 clinical diagnosis based on hematological parameters" proposes the use of Evolutionary Computing and Machine Learning techniques to automate the analysis of hematological parameters for the rapid diagnosis of COVID-19.

Construction of Phylogeny Tree



- Phylogeny: an explanation of how things evolved, their evolutionary relationships between “taxa” (entities such as genes, populations, species, etc.)
- Phylogeny reconstruction by sequences

How to construct a phylogeny

1. distance data

	1	2	3	4	5	6	7
1. Ath							
2. Bra	0.027						
3. Gma	0.239	0.244					
4. Vvi	0.216	0.205	0.164				
5. Osa	0.452	0.444	0.492	0.399			
6. Mtr	0.227	0.227	0.063	0.134	0.475		
7. Ptr	0.239	0.250	0.139	0.154	0.475	0.116	

- **UPGMA**
- **Neighbor-joining**

2.discrete characters

Species/Abbrv △	Gr		*	*			*				*	*	*		*	*		*	*	*		*
1. Ath		E	M	M	N	S	L	S	H	I	F	R	W	E	L	L	V	G	E	R	Y	G
2. Bra		D	M	M	N	S	L	S	H	I	F	R	W	E	L	L	V	G	E	R	Y	G
3. Gma		D	M	M	N	S	L	S	Q	I	F	R	W	D	L	L	V	G	E	R	Y	G
4. Mtr		D	M	M	N	S	L	S	Q	I	F	R	W	D	L	L	V	G	E	R	Y	G
5. Osa		D	M	M	A	A	L	A	G	L	F	R	W	D	L	L	L	G	E	R	F	G
6. Ptr		E	M	M	N	S	L	S	Q	I	F	R	W	D	L	L	V	G	E	R	Y	G
7. Vvi		D	M	M	N	S	L	C	Q	I	F	R	W	D	L	L	V	G	E	R	Y	G

- **Parsimony**
- **Maximum Likelihood**
- **Bayesian Methods**

Log likelihood of different topology

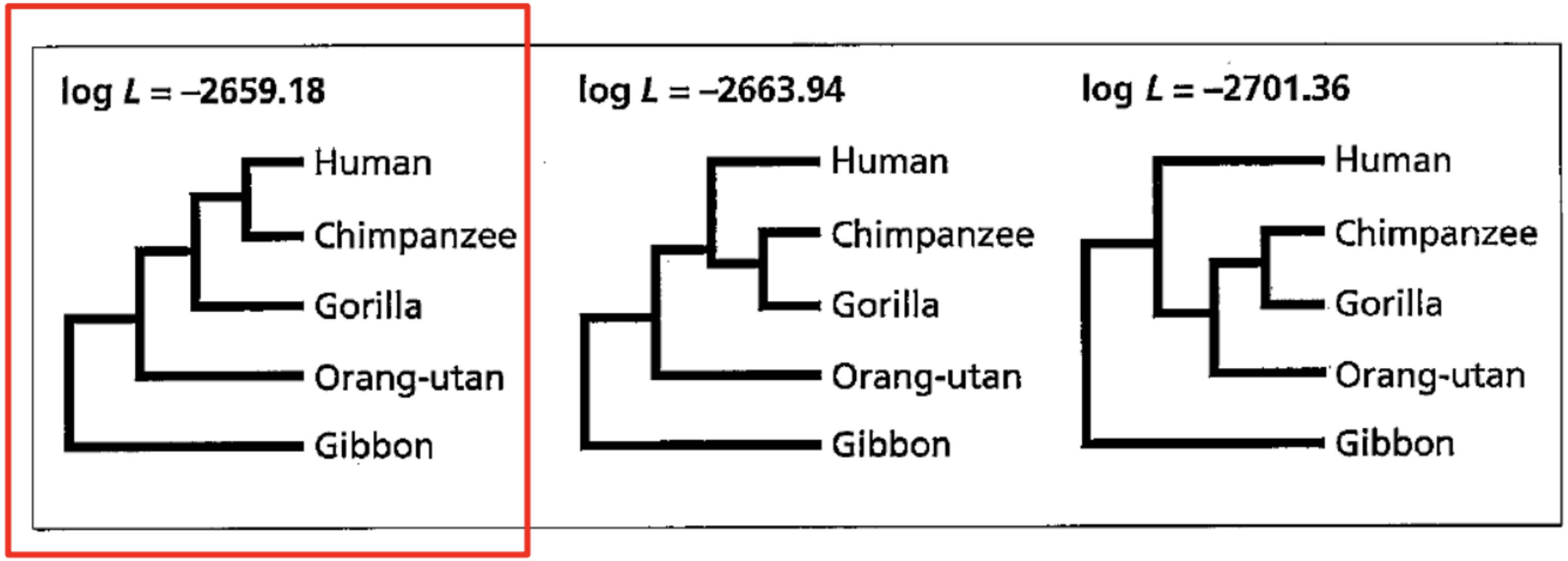


Fig. 6.19 Three different hypotheses of relationship among the hominoids and the likelihoods that each tree has given rise to the observed data.

Some Tools

- MEGA (Molecular Evolutionary Genetics Analysis)
  https://www.megasoftware.net/
- BEAST (Bayesian Evolutionary Analysis by Sampling Trees)
  https://beast.community/
- RAxML (Randomized Axelerated Maximum Likelihood)
  https://github.com/stamatak/standard-RAxML
- Biopython (Biological Computation in Python)
  https://biopython.org/
- scikit-allel (Genomic Selection & Population Genetics)
  https://scikit-allel.readthedocs.io/en/stable/
- MSMS (Forward-in-Time Simulation of Selection in Populations)
  https://www.mabs.at/ewing/msms/

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