The Riot and the Dance

THE RIOT AND THE DANCE

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To my lovely wife Meredith,
my helpmeet, joy, and crown

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PART 1

THE LIVING CELL

CHAPTER 5

ORGANELLES

OF THE EUKARYOTIC CELL

In my overview of the eukaryotic cell I will liken it to a factory. Cells are not static, they are very dynamic—like a factory. They are carrying out many different activities, and they require the energy and materials to do so. They bring in raw materials, and with them build many different products using various machines. They also need design templates to manufacture the various products to be made. They need employees (factory workers) that run, maintain and operate the machinery. They need transport vehicles to carry raw materials as well as partially or completely assembled products around or out of the cell. Because of these similarities I will use factory terminology to summarize the functions of the important organelles or organelles common to all cells.

CYTOPLASM

Cytoplasm is simply the fluid of the cell (cyto = cell; plasm = fluid). As I mentioned before, cells are very complicated microscopic water balloons. It is the watery or gel-like matrix in which the organelles move about or are suspended in. It is 80-95% water with many dissolved biomolecules in it. Among these molecules are important ions, biomolecules used for fuel or for raw materials needed for manufacturing products, and the biomolecules that function as the factory workers. The latter are the mighty enzymes (catalytic proteins) performing many of the demolition or manufacturing reactions in the cell. There are hundreds of different kinds of enzymes and each has a very specialized job description. An assembly-line worker that screws in one kind of bolt is a good approximation of one kind of enzyme. I will discuss enzymes later on in more detail.

NUCLEUS

The **nucleus** is a relatively large organelle that is often in the middle of the cell but may be situated off to the side depending on the type of cell. It is exceedingly important in that it contains all the genetic information of the cell. In factory-speak, it would be the executive offices where all the design blueprints are stored. Of course the blueprints themselves are not made into a particular product. Rather, the information in the blueprints are scrupulously followed by the production engineers and 'whatever the plans' specify is made into a tangible product like a car engine. In the cell, the design blueprints are contained on the biomolecule called DNA. As a quick preview, the tangible product is protein. Later we will discuss the nitty-gritty of how the DNA code is translated into protein. The boundary of the nucleus is called the **nuclear envelope**. We have mentioned previously the substance of biological membranes (phospholipid bilayers). Well, the nuclear envelope is a two-ply phospholipid bilayer, that is, a bilayer of bilayers. This envelope is also perforated. The inner and outer bilayers connect to form openings over the surface of the envelope giving it a whiffle-ball appearance. These holes allow, among other things, the movement of RNA ('xeroxed' copies of certain sections of the blueprints i.e. DNA) out of the nucleus (executive offices) and into the cytoplasm (the factory floor). This enables the various cellular factory workers to have access to the blueprints so that they can build the product according to code (genetic code, that is).

As I have said, just about everything inside living things is wet. That also goes for the nucleus. The watery fluid of the nucleus is called the **nucleoplasm**. The DNA and other important molecules are dissolved in the nucleoplasm. So what is DNA, actually? Many people have heard the term chromosome but aren't sure how it relates to DNA. You are probably familiar with the term 'skein' if you have anybody in your family that knits. If not, here you go: a skein is a sausage- shaped bundle of yarn coiled up in an orderly fashion so as to minimize tangling as it's unwound. Your chromosomes are like miniature skeins of DNA. You have 46 chromosomes (skeins of DNA) per nucleus. You have a double set of genetic information since you received an entire set from your father's sperm (23 chromosomes) and an entire set from your mother's egg (23 chromosomes). Recall when we discussed biomolecules, DNA is an exceedingly long molecule made of millions of nucleotide building blocks. It is a double helix with two chains of nucleotides twisted around each other such that the nitrogenous bases in the middle form the 'rungs' between the chains. With high powered

microscopes it is possible to see a darkly stained area within the nucleus which is called the **nucleolus**. This is an area that is actively engaged in the manufacture of certain parts of ribosomes.

RIBOSOMES

We will get into the details on ribosomes later on, but for now, suffice it to say that **ribosomes** are complex assembly platforms for making proteins. The RNA ('xeroxed' copies of certain sections of DNA blueprints) move out into the cytoplasm and are fed through ribosomes. As the RNA instructions are 'read' by the factory workers (enzymes) at the ribosome, the RNA nucleotide sequence specifies the sequence of amino acids to be hooked together. This is a quick overview of how DNA codes for life. DNA codes for RNA, which in turn codes for proteins. The types and amount of proteins made in a particular cell determine the structure and function of that cell. Getting back to the factory cell analogy, the blueprints (DNA) not only code for much of the structural parts of the cell factory but also the functional parts. In other words, certain sections of the DNA code for factory machines, for much of the supporting framework of the building and also for the factory employees (enzymes). (These employees aren't hired on from the outside; they are factory-made employees.)

ENDOPLASMIC RETICULUM

After a piece of RNA is fed through a ribosome and a brand new protein is made, it is not necessarily 'ready to roll'. It may require further processing in one or more cellular assembly lines. One of the first organelles that a protein usually enters is a maze-like network of membranes filled with many enzymes designed to manipulate and modify a new protein. This organelle is called the **endoplasmic reticulum** (ER) (endo=inner; plasm=fluid; reticulum=network). The ER enzymes stick various molecules on specific parts of a protein chain so that it will be equipped to carry out its particular function when it is finally deployed (for example, an oligosaccharide chain may be tacked on the new protein so that it can serve as an identification sticker on the cell's surface). The ER may also attach a molecule that serves as a 'mailing address' so that the protein can be delivered to the correct location in the cell (another organelle which will act like another assembly line) for further processing. If the protein is complete and 'ready to roll,' it is then delivered to its final destination for deployment. If the ER is heavily

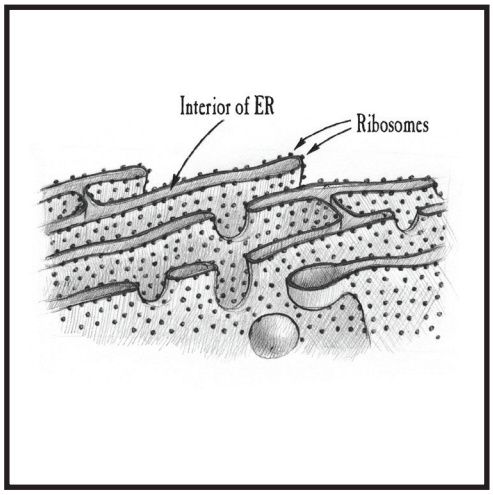

Figure 5.1 Rough endoplasmic reticulum

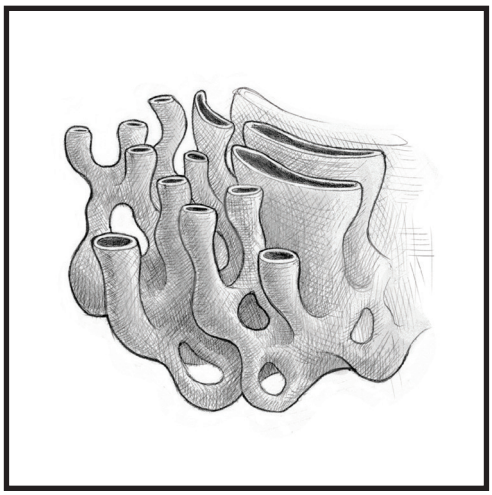

Figure 5.2 Smooth endoplasmic reticulum

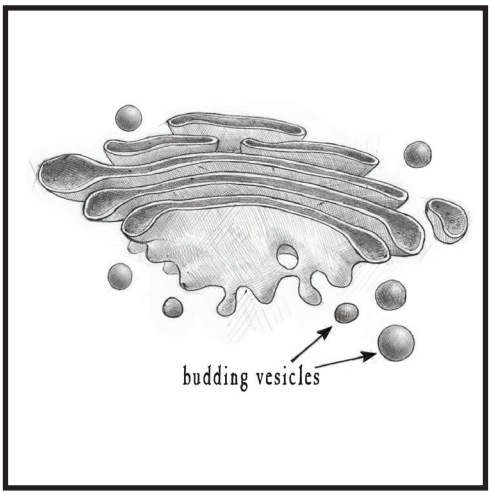

Figure 5.3 Golgi body

involved in processing freshly made proteins from ribosomes, its outer surface will be peppered with ribosomes. When electron micrographs (photographs taken through an electron microscope) reveal a bumpy surface on the ER due to its generous coating of ribosomes, it is called **rough ER**.

Another endoplasmic reticulum that is not studded with ribosomes is called the **smooth ER**. Because it lacks ribosomes it is not as heavily involved in protein processing as is the rough ER, but it may be involved in the further modification of proteins received from the rough ER. The smooth ER typically has a team of enzymes designed to either manufacture lipids from scratch or remodel existing lipids.

GOLGI BODY

The **Golgi body** is a peculiar organelle that looks like a stack of deflated beanbags. They have several functions, one of which is protein processing. When thus occupied the Golgi body receives membrane-bound packages loaded with proteins (from either the rough or smooth ER) that still need a few final touch-ups before they are turned loose as fully functional proteins. For instance, the Golgi body makes final modifications to glycoproteins (proteins with carbohydrate side chains) from the rough ER. In plants, Golgi bodies

often have enzymes that are employed in the manufacturing of cellulose (a common polysaccharide) from glucose units (a common monosaccharide). If you recall, the reaction which hooks glucose units together is called a *dehydration synthesis* reaction. Cellulose is the major ingredient of plant cell walls. Virtually every plant cell has a cell wall outside of its cell membrane. This means that plant Golgi bodies are quite busy manufacturing plant cell wall material (cellulose). Once cellulose is made in the Golgi body, it must be packaged in a vesicle and shipped to the cell membrane to be dumped outside of the cell. This is accomplished by the aforementioned process called exocytosis. In Figure 5.4, cellulose is being exocytosed from a vesicle made at the Golgi body.

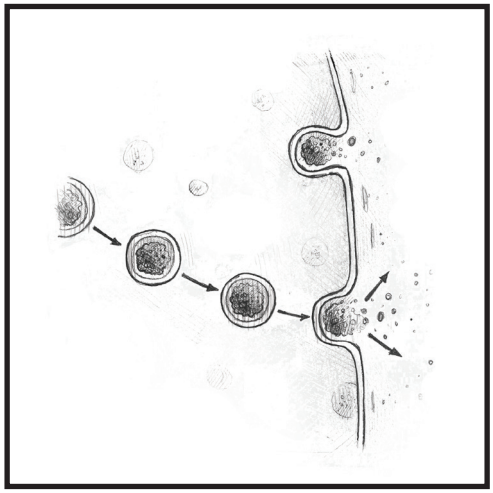

Figure 5.4 Exocytosis of cellulose

When a particular cell needs to make and export digestive enzymes, again, exocytosis is the preferred method by which its enzymes exit the cell. In short, the Golgi body is involved in modifying, packaging, and shipping various biomolecules to other organelles or the cell membrane.

LYSOSOMES

It is not good to keep facts about these various organelles in completely separate vacuum-sealed compartments in your brain. As you have already seen, some organelles are closely related, interact with each other, or produce one another. Lysosomes are one such example of the latter: **lysosomes** are begotten by the Golgi body if the Golgi was engaged in the manufacture of digestive enzymes. Once the digestives enzymes are ready to be deployed, the Golgi body buds off a vesicle (a lysosome) filled with a variety of digestive enzymes designed to hydrolyze (break apart) most of the major biomolecules. Lysosomes receive a shipping address so that the cellular transportation system (more on this later) will ship it to its proper destination. Some of these destinations include the cell membrane (exocytosis). An example of this is found in cells lining your digestive tract. As chewed up steak, mashed potatoes, and gravy leave your stomach, bazillions of cells lining the inner surface of the small intestine actively dump (exocytose) digestive

enzymes into the lumen (empty space) of the intestine. How? These cells had been diligently manufacturing digestive enzymes in their Golgi bodies, and they packaged those enzymes up in lysosomes and sent them to the cell membranes that face the lumen. Gazillions of lysosomes are then exocytosed (imagine them exocytosing their digestive enzyme contents). The enzymes are dumped out of the cell and into the lumen in which the food is sloshing along. The proteins, carbohydrates, lipids, and nucleic acids that compose the bulk of the steak, mashed potatoes, and gravy are attacked by the digestive enzymes. Eventually the meal is liquefied because the enzymes digest almost everything down to the basic building blocks (amino acids, monosaccharides, monoglycerides, fatty acids and glycerol, etc).

Sometimes the lysosomes have a destination within the same cell. Certain organelles get too old and shabby becoming a liability to the cell's proper functioning. For instance, if a mitochondrion has too many miles on it, its diminishing performance makes it a candidate for forced retirement and demolition. Consequently, a lysosome is shipped to it, it fuses with the mitochondrion, the digestive enzymes break it all down and its nutrients are used by the cell as needed.

If a cell (often unicellular organisms or a white blood cell) phagocytoses a food particle, the resulting vesicle is called a **food vacuole**. Of course the food particle needs to be digested for it to be of any use to the cell, so once again, it's a job for a lysosome. The lysosome is shipped to the food vacuole and fuses with it. The enzymes then wreak havoc on the food particle, digesting all the biomolecules down to their basic building blocks. Another interesting use of lysosomes is programmed cell death (apoptosis). When we were tiny embryos within our mother's womb, our hands looked like paddles because our fingers were stuck together. In a highly regulated process, the cells that form the webbing between our fingers undergo *programmed cell death*. In other words, the lysosomes release their destructive brew with in the cytoplasm resulting in cell death and disintegration. When certain cells do this between the fingers, the fingers physically separate. It is much more complex than it sounds, but that is the gist of it. The last use I will mention later when I discuss food vacuoles.

MITOCHONDRIA

Within each cell are usually dozens of jelly-bean shaped organelles called mitochondria. For some reason this is the organelle that many students vaguely recall from their high school biology class. It does have a nice ring

to it. We will discuss some of the metabolic reactions that occur in its innards later on. But for now, these organelles are power plants of the cell generating a usable form of energy for most cell activities that require energy. All electrical power plants require an external energy source, whether it is the burning of coal or the flow of water through the turbine within a hydroelectric dam. In the eastern US there are many coal-powered plants that produce a lot of energy for that part of the country. In fact, many personal computers are run from the electricity produced by burning coal. The point I'm making is a computer may be coal powered but not by shoveling coal into the disc drive and lighting a match to it. The burning of coal releases heat energy but it has to be first converted into a usable form of energy (electricity). It also has to be converted to a usable form of electricity that is compatible with the power cord on the computer. The energy currency used by the cell, as mentioned earlier is ATP not a Snickers bar (although a Snickers bar may ultimately power your cells). In short, whether it is a unicellular creature or a cell within a multicellular creature, cells need energy (just like your computer) if they are to do anything (like keep you alive). Food (like coal to the power plant) is ultimately the source of energy for cells (usually sugars and lipids) but this food is not in the right form for the cell to use directly. The cell must first convert the energy stored in food and harness that energy to make ATP. Most burning requires oxygen.

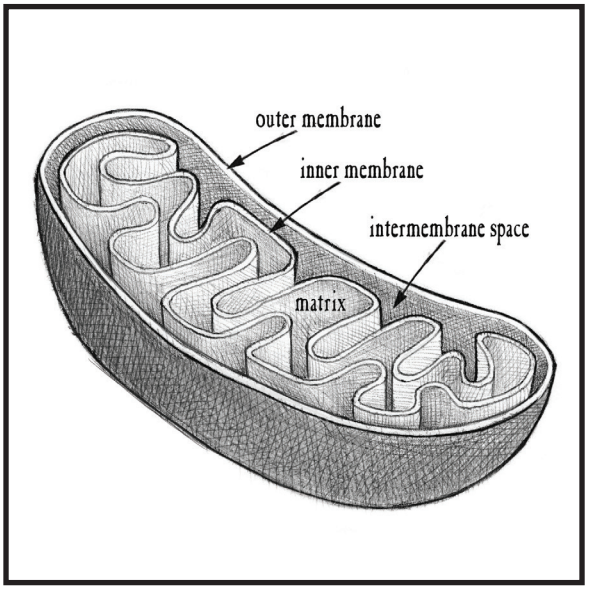

Figure 5.5 Mitochondrion

Whether wood, coal, oil, gas, or food is burned, oxygen is necessary for the combustion to occur. Consequently, all your cells (particularly the mitochondria) need a constant supply of oxygen to burn food and make ATP. Then the mitochondria 'burn' the sugars and lipids into biological exhaust, which are CO_2 and H_2O.

Power plant: oxygen + coal →→ smoke and ash + energy (electricity)
Mitochondrion: oxygen + food →→ CO_2 + H_2O + energy (ATP)

By the way, your respiratory system is your exhaust system and your mouth and nose are your exhaust pipes or smoke stacks. That means (are you ready for this?) a large part of your food is ultimately exhaled out of your mouth and nose. Yes, you lose weight by just breathing. Part of the burning process occurs in the cytoplasm but it's finished in the mitochondria. During this burning process, the energy in the food (sugar and lipids) is released and captured by the mitochondrion. During the 'burn,' the mitochondrion is charged up like a miniature acid battery which is then able to produce ATP (high energy) from ADP and P (low energy). An analogy of this would be like a battery recharger (the mitochondrion) recharging dead batteries (ADP and P) into fully charged batteries (ATP). The details will come later (whether you like it or not). Of course the battery recharger needs to get energy, so that's why it is plugged into the wall. The mitochondria get their energy by burning food, so that's why you eat: so your mitochondria can 'recharge' their batteries (ATP).

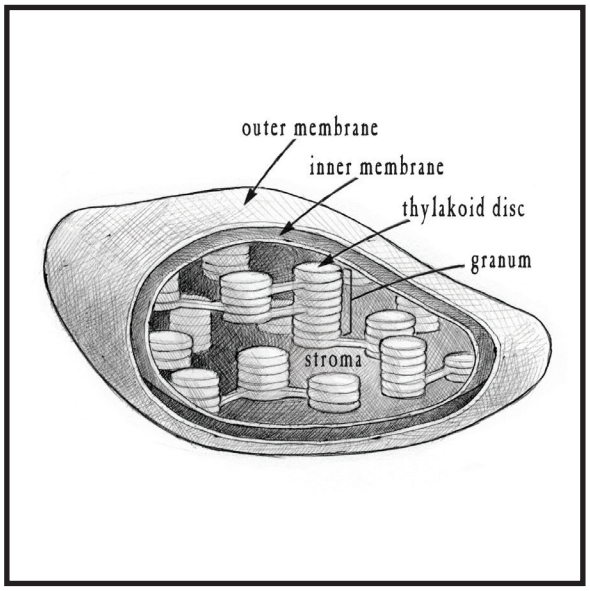

Figure 5.6 Chloroplast

CHLOROPLASTS

Chloroplasts are bright green organelles that are responsible for carrying out the amazing process of photosynthesis. Consequently they are found in photosynthetic organisms like plants, algae, and blue-green algae. The major reason why most stems and leaves are green or greenish in appearance is that most of the cells in them are jam-packed with chloroplasts. Chloroplasts are green because their internal membranes are loaded with the green pigment called chlorophyll. In most respects chloroplasts do the exact opposite of the mitochondria. While mitochondria burn sugars (and lipids) into CO_2 and H_2O to generate ATP, chloroplasts, conversely, use the sun's energy (and ATP) to build sugars from the simple ingredients of CO_2 and H_2O. See how their ingredients and products are just the reverse, except that sunlight is in the place of ATP as the energy.

Mitochondrion: oxygen + food →combustion→ CO_2 + H_2O + energy (ATP) (Burning sugar releases energy)

Chloroplast: CO_2 and H_2O + energy (sunlight) → building → sugar + oxygen (by product) (Building sugar requires energy)

What is really amazing about plants (and other photosynthesizers) is that they can make the vast majority of their body out of thin air! Yes, they do need a few minerals from the soil, but these are miniscule amounts compared to their entire mass. Most of their tissues (which include many different types of compounds) are predominantly derived from the glucose, the basic product of photosynthesis. Glucose is constructed from two colorless and odorless compounds that came out of thin air, CO_2 and H_2O. The CO_2 is a small percentage of the atmosphere and H_2O is also in the atmosphere. Of course the H_2O condenses to form clouds, the clouds produce rain, the water goes into the soil, then into the plant roots, up their stems, into their leaves, into their plant cell's chloroplasts, and lastly reconfigured (along with CO_2) into the glucose. Think about it: a California Redwood is primarily made from thin air through the magic of photosynthesis.

VACUOLES

Vacuoles are a 'catch all' term for any membrane bound organelle having a variety of sizes and shapes that share the function of storage container for a variety of contents. The content varies because different cell types have different needs to store many different substances. For instance, fat cells are ministorage vats for lipids, so they have relatively large vacuoles completely filled with triglycerides. (These are called lipid vacuoles.)

After an ameba phagocytoses a smaller critter (often bacteria) for food, it becomes encased in a membrane. The resulting vesicle containing the victim is called a food vacuole. This prey item needs to be digested, so the next order of business is to ship a lysosome to this food vacuole. When the lysosome contacts the food vacuole, it fuses with it. The digestive enzymes then flood around the miniature prey and it is promptly reduced into a nutrient soup. This soup is then absorbed across the vacuole membrane and into the cytoplasm for the ameba's sustenance. After these goodies are absorbed, some waste may remain within the vacuole. At this point the vacuole is storing waste and is thus renamed **waste vacuole** (I hope I didn't insult your intelligence). The waste vacuole needs to do a 'dump run' which consists

of the vacuole being transported to the cell membrane for *exocytosis,* thus dumping the waste outside the cell.

Because non-woody plants don't have a skeleton to hold themselves up they need to maintain high fluid pressures (turgor pressure) within their cells. When this is necessary, plant cells often have large central vacuoles that hold mostly water to maintain a fairly high internal pressure which makes the cells turgid.

Yet another type of vacuole belongs to certain unicellular critters which live in freshwater environments. They have a specialized container called a **contractile vacuole**. Because they live in a hypotonic environment, they are constantly absorbing water by osmosis. Recall that this is because the water concentration is high on the outside compared to the water concentration on the inside (more solutes dissolved in the cytoplasm). Water flows from high to low along its concentration gradient causing the cell to gain water. This would continue until the cell bursts (cytolysis) like a water balloon left on the faucet too long. But the contractile vacuole is essentially a nano-water-bailing machine or sump pump. Minute membranous canals absorb excess water throughout the cell and deliver it to the contractile vacuole. When it inflates to a certain volume, contractile proteins surrounding the vacuole contract, squeezing the vacuole much like the muscles surrounding your distended bladder cause you to lunge for the bathroom. This forces the water to the outside world through a tiny membranous canal linking the contractile vacuole to the cell membrane, ridding it of excess water. This regularly occurs since the cell is constantly gaining water by osmosis.

Figure 5.7 Cytoskeleton

CYTOSKELETON

As the name implies, the **cytoskeleton** is the skeleton of the cell. Our bones form a skeleton which grants the rest of our flesh a supporting framework to hold us up and provide a system of levers enabling us to move. Without it we would be a big pile of quivering flesh, which would soon die. In much the same way the cytoskeleton forms a supporting framework within the cell granting the cell a certain shape. Another

analogy would be tent poles. These wonderful, lightweight, flexible rods can be fitted together to form an internal (don't think of external tent poles) framework to grant a certain shape to the tent. This web-like cytoskeleton gives this nerve cell (neuron) its peculiar shape (Figure 5.7).

In addition to the cytoskeleton granting a certain shape to the cell, the cytoskeleton can also provide a system of cellular cables along which vesicles, vacuoles, and other organelles get ferried around the cytoplasm like trolleys or gondolas (Figure 5.8).

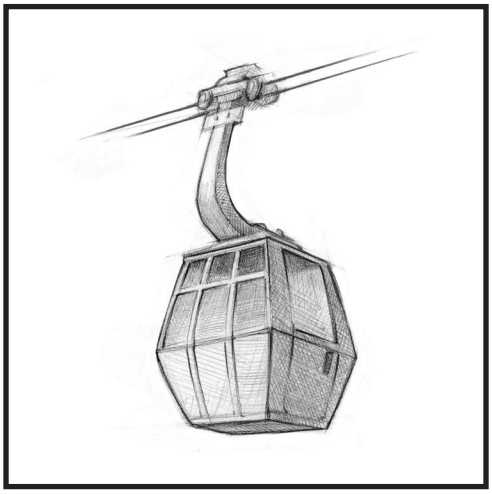

Figure 5.8 Gondola analogy

There are a number of different kinds of cytoskeletal fibers. I will briefly mention three. As I've mentioned before, proteins are ubiquitous and of paramount importance in the economy of the cell so it's not surprising that the cytoskeleton is made of protein.

MICROTUBULES

Microtubules are the largest of the three cytoskeletal elements. They have an appropriate name because they are small and are hollow like a tube. They are made of many repeating units of a type of protein called tubulin. Each tubulin protein is actually two polypeptide chains hooked together to form a single subunit. Each tubulin subunit fits together with other tubulin subunits much like Legos fit together. Their 3D shape causes them to fit together to form long hollow tubes or cylinders. These long microtubules serve the cell by being the aforementioned trolley or gondola cables for the movement of organelles and, during mitosis, chromosomes. Microtubules also form the internal framework of the locomotive organelles called flagella and cilia. Both flagella and cilia have a similar parallel arrangement of 20 microtubules. There are two single microtubules in the flagellum center and nine sets of paired microtubules surrounding them. This set of tubules doesn't just serve as a cellular skeleton; it actually forms a dynamic motor in which the microtubules (which are tethered together by another protein called nexin) are forcefully ratcheted past each other by motor proteins called *dynein*. This ratcheting past each other while still being loosely

tethered will cause the whole system of microtubules to bend. And this bending back and forth causes the well known wriggling movement of flagella and cilia, which enables a free cell to swim or a fixed cell to sweep something past.

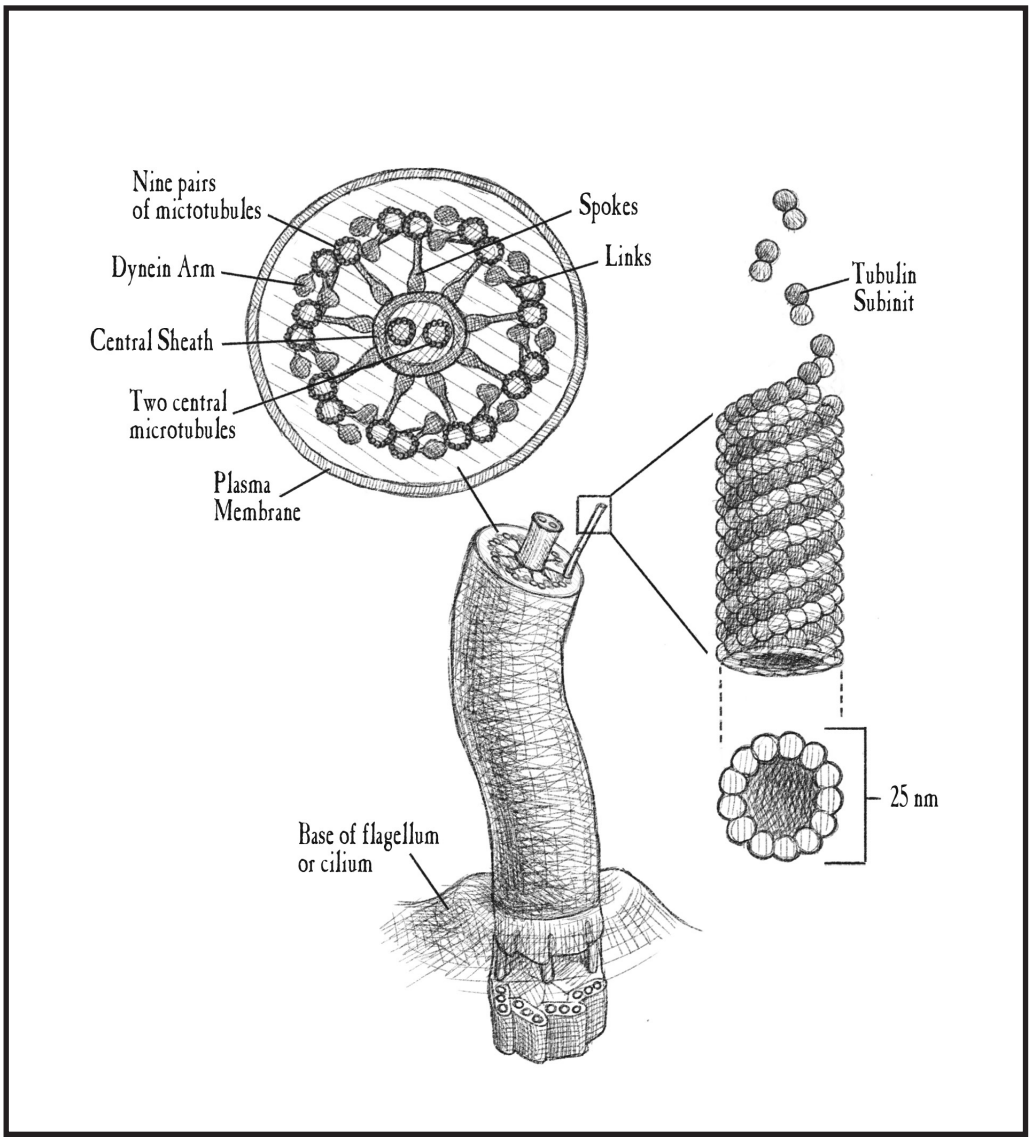

Figure 5.9 Flagellum or cilium structure

INTERMEDIATE FILAMENTS

These tiny tent poles are 1/2 to 1/3 the diameter of microtubules and appear to only have structural roles that help shape the cell rather than provide transportation services like microtubules do. **Intermediate filaments** are not

composed of globular proteins, but rather of long fibrous proteins bundled and twisted together like fibers in a rope.

MICROFILAMENTS

Microfilaments are the smallest of the cytoskeletal elements, but are one of the most abundant and widespread proteins in the cytoplasm of eukaryotic cells. Depending on its form, a **microfilament** can simply serve as a structural framework in a cell (tent poles) or be a very important team member in the complex contraction system within all types of muscles cells. It is also found in other nonmuscle motility systems in other cells. The main component in microfilaments is the globular protein called *actin*. One actin protein is called a subunit. Many actin subunits chain together like pop-it beads. Two chains of actin subunits are braided together to form a microfilament.

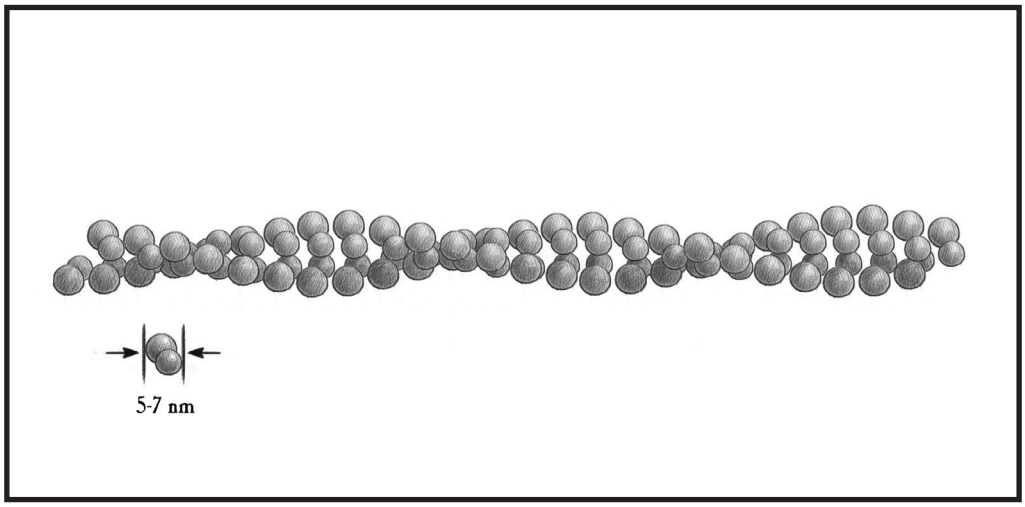

Figure 5.10 Microfilament

CELL WALL

Cell walls, if present, are found outside the cell membrane. They provide external rigid or flexible support for the cell. A simple model for this would be a trash can with a plastic trash bag lining it. The trash bag is the flexible cell membrane. The trash can, which is holding up the bag and giving it shape, is the cell wall. Since cells are filled with fluid cytoplasm, it would be more akin to a trash bag filled with water within the trash can. Without the can, the water-filled bag would bulge out to form a roundish water balloon. However, inside the can the water-filled bag would exert pressure on the

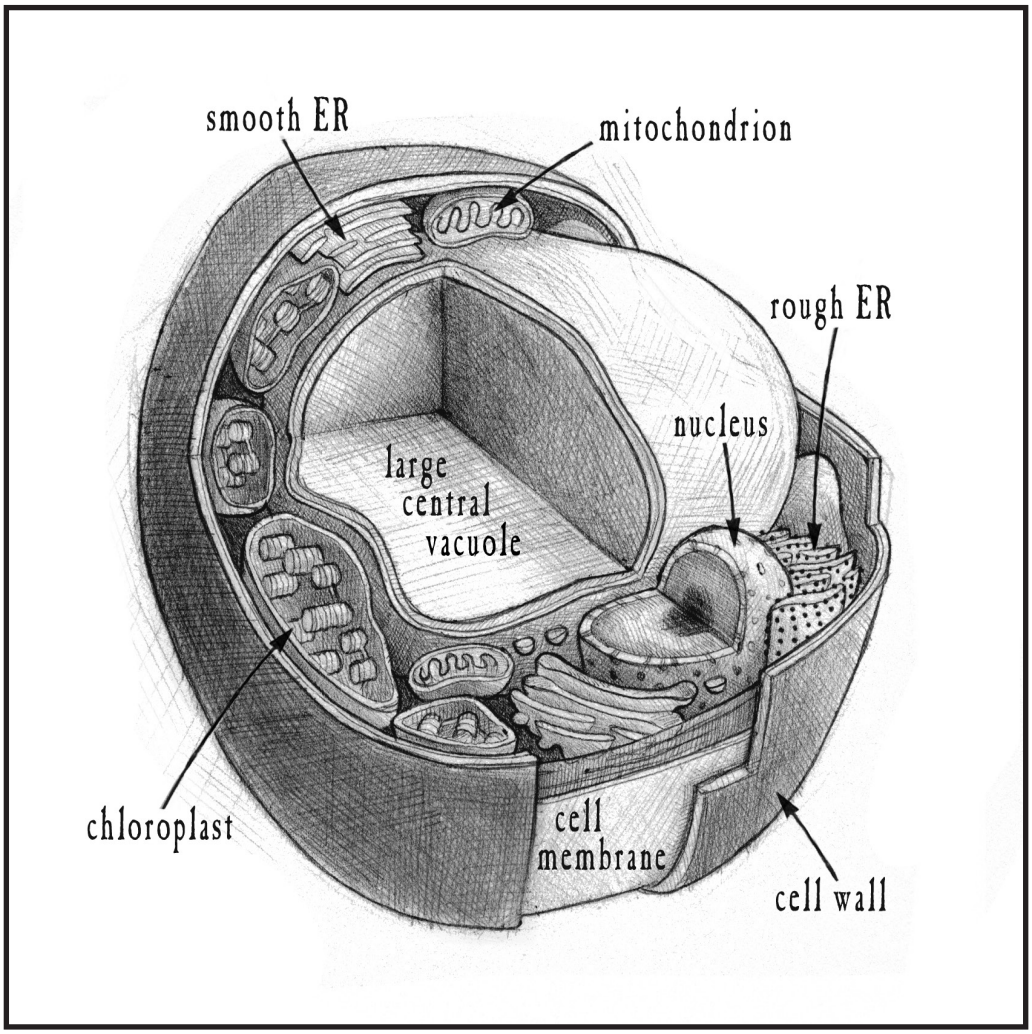

Figure 5.11 Plant cell

trash can walls but would still conform to the shape of the can. If the can is rectangular, then the bag will be as well. Plant cells, fungal cells, bacterial cells, and algal cells all have cell walls and because these are very diverse groups, it is no surprise that the main materials making up the cell walls are different. Most cell wall material is a polysaccharide of some stripe. Plants and most types of algae have cell walls made mostly of *cellulose*. Fungal cell walls are made of the polysaccharide *chitin*. There is another unique polysaccharide cross-linked with short oligopeptides called *peptidoglycan*. This stuff makes up bacterial cell walls. Animal cells don't have cell walls. The fact that plant tissue in salad is somewhat crisp testifies to the fact that its cells have cell walls. The higher the water pressure is within the cell wall, the more turgid the cell becomes. Recall the analogy of air pressure

in a tire. The air pressure (psi) would be like the water (turgor) pressure within each cell. The inner tube containing the air would be like the cell membrane containing the cytoplasm. The thicker, more rigid tire would be like the cell wall. The higher the turgor pressure, the more crisp the salad. The satisfying crunch comes from both the semi-rigid cell walls as well as the turgor pressure contained within each cell. When you bite, say, a celery stick, your teeth are rupturing myriads of cell walls and consequently these cells, under high pressure are popping. The satisfying crunch of celery is actually the sound of thousands of cells exploding under pressure. When we eat meat (muscle tissue) it is not crunchy (if we don't leave it on the grill too long) because the muscle cells don't have cell walls. Therefore muscle cells can't be under pressure. If they were, they'd pop.

Compared to cell membranes, cell walls are much more rigid. This enables cell walls to provide structural support and to resist varying degrees of mechanical stress. The degree of support and strength depends upon each cell wall's composition and thickness. For example, wood cell walls are much more rigid because they are thicker and have a solidifying compound called *lignin* mixed in with the cellulose. This makes wood cells much stronger than ordinary plant cells and provides enough mechanical support to allow trees to grow very tall. Nevertheless, cell walls are also much more porous than cell membranes.

In other words, they are stronger but leakier. Many substances can pass right through them. By analogy, plastic screening is much more flexible than a chain link fence, but it is also much more selective about what substances can pass through it. Pea gravel is stopped by a thin, flexible screen but it can fly right through a sturdy chain link fence.

OTHER STUFF OUTSIDE CELLS

If it is not cell membrane or cell wall and is outside the cell, it is called **extracellular material**. This stuff is also very diverse in form, function, and composition. It is usually a mix of polysaccharides and proteins and can be found in plants, animals, fungi, protists, and bacteria.

In bone, the cells are not packed together. Rather an extracellular mix of protein (collagen) and a solidifying compound called hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$] provides a fairly rigid matrix surrounding all the bone cells. It is kind of like lots of little water balloons (bone cells) embedded in concrete (extracellular material).

The arrangement is similar in cartilage except that the extracellular material is much more flexible. It has much of the same protein (collagen) but doesn't have the hydroxyapatite to make it rigid. It would be more comparable to water balloons (cartilage cells) embedded in Jell-O (extracellular material).

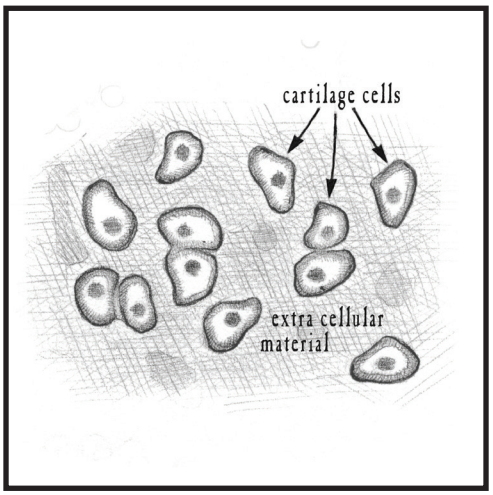

Figure 5.12 Cartilage

In the two examples above, neither had cell walls, but they still had extracellular material. However, on the surface of leaves, the cells have not only cell walls (like all good plant cells) but also extracellular material called a cuticle. This stuff is high in wax content, among other things, and is thus quite water proof. The cuticle overlays the surface of cells like a fresh coat of wax on a tile floor. Leaves are high in water content, so without the waxy cuticle the water would evaporate from the leaf very quickly, causing the leaf to wilt and die unless it was watered constantly.

STITCHING CELLS TOGETHER

Multicellular creatures, though made of millions, billions, or trillions of cells, are knit together so that they don't burst into a cloud of cellular dust in the face of a stiff wind. It would be a drag if our bodies disintegrated in the bathtub like a sand castle at high tide. Why don't they?

Fortunately God equipped us to stitch our cells to together as we develop from a one-celled zygote to a many trillion cell adult. The stitching is accomplished by special membrane proteins on adjacent cells that hook together thus riveting the cells together wherever the proteins are. These are called **tight junctions**. Another group of proteins forms a tunnel called a **gap junction** that spans both membranes of the adjacent cells. This isn't just riveting the cells together, it also creates a corridor through which cytoplasm can flow from one cell to the other without ever leaving a cell. This would be analogous to a single door jam spanning the adjacent outer walls of two townhouses, so that you could walk from one home to the other without going outside. Another type of junction looks like protein 'buttons' mounted on the inside surface of two adjacent cells (the buttons are lined

up) and fibrous proteins stitch one 'button' to the other, linking the two cells to together. This type of junction is called a **desmosome**. (Keep in mind that there are several kinds of desmosomes, tight junctions, and gap junctions.)The significance of gap junctions become apparent once we realize that cells need to chemically communicate with each other. This communication enables cells, tissues, and organs to work together as coordinated and integrated wholes. And these wonderfully integrated wholes we call creatures. But we'll save that realization for another day.

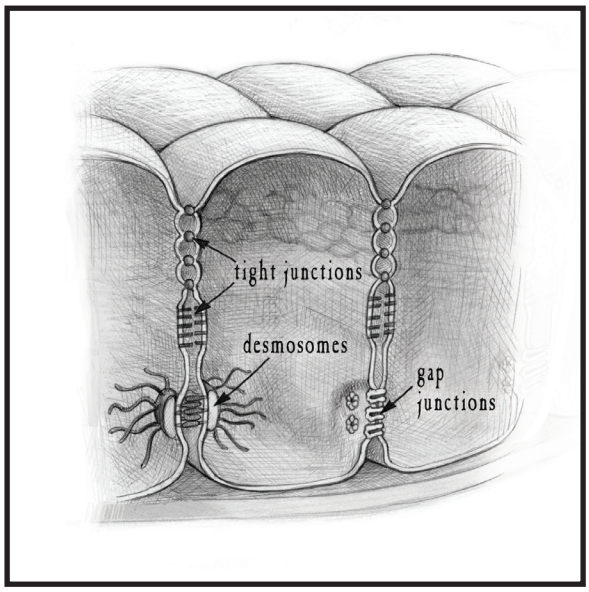

Figure 5.13 Cell junctions

CHAPTER 5: REVIEW QUESTIONS

1. The _____ contains the vast majority of DNA and is covered in a _____ -layered envelope containing pores.

2. _____are tiny organelles used in the construction of proteins.

3. The _____ is involved in the modification of newly made proteins.

4. The fluid of the cell is called the _____.

5. The organelle that 'burns' food to make ATP for the cells' energy needs is the _____.

6. The organelle that captures sunlight energy to make glucose out of carbon dioxide and water is the _____.

7. The organelle involved in modifying, packaging, and shipping various biomolecules to other organelles or the cell membrane is the_____.

8. An organelle that contains digestive enzymes for the demolition of various biomolecules is the _____.

9. Various proteins that form internal ‘tent poles’ or form internal transport rails throughout the cell are called the _____.

10. The semi-rigid supporting framework outside the cell membrane is called the _____.

PART 2

DIVERSITY OF LIFE

PART 2

INTRODUCTION

In Part 1 I presented an overview of the cell's structure and function. Of course, it was a blow-through tour. There are many other parts and processes that occur in cells, but I covered the bare essentials traditionally presented in other introductory texts, to give you a basic understanding of how entire cells work. If Part 1 could be likened to how engines work, then Part 2 is an overview of the common makes and models of vehicles that are out on the market.

CHAPTER 15

CLASSIFYING LIFE

Categorizing living organisms at first glance might seem to be fairly straightforward, like how you might go about organizing a tool box: screwdrivers here, hammers there, crescent wrenches under here, and so on. Unfortunately, it's not that easy. It's more like organizing every Lowe's and Home Depot. . . nationwide. People have been trying to classify life for millennia and it still remains a troublesome affair.

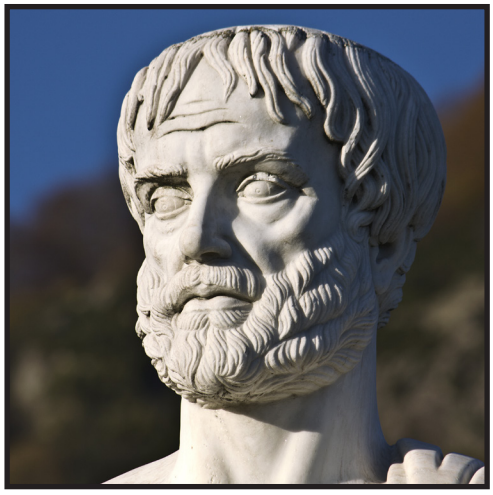

Figure 15.1 Aristotle

Aristotle was a considerably astute naturalist and employed his acumen and logic in a close and detailed examination of many living creatures (although many were dead at the time of examination). As is the goal of most taxonomists, his goal was to create natural groupings according to the features they have in common.

Aristotle was keenly aware that the criteria one uses greatly affects the outcome of the classification scheme. He wanted to avoid artificial groupings (e.g., black animals) because they tend to ignore so many other fundamental characteristics. Instead, he attempted to group creatures to reveal the order implicit in nature, rather than impose an artificial grouping contrary to nature.

For example, artificial groupings based on the coloration of hair, skin, fur, or plumage will result in strange bedfellows, such as black rat snakes, black widows, crows, and black bears. Or if you group together any insect over two inches long, you'd get a motley assortment of big beetles, big roaches, big grasshoppers, big walking sticks, etc., and never arrive at a natural grouping of just beetles.

These examples may seem intuitively wrong but why? We might have greater success at a natural grouping if we selected a pair of characteristics that are less superficial, say, warm-blooded egg-layers. This is definitely closer to the mark of a natural rather than artificial grouping but it still doesn't include enough characters to define birds apart from everything else. There are two warm-blooded egg-laying mammals which would be classified as birds if we used only those two characters.

In short, it's not all that simple. In order to sort the diversity so that it reflects the *true* order of nature, it is of paramount importance that we choose the characteristics that *reveal* that order. This isn't as easy as it may seem.

And, of course, exacerbating this problem is the sheer number of species: right now, around 1.4 million. This includes the known extant species of plants, animals, protists, fungi, archaebacteria, and eubacteria. But due to the fact that many unknown species are very small or even microscopic, live in exotic, out-of-the-way places, are too difficult or expensive to study, or are simply not interesting enough to attract attention (or all the above), the real number of species is probably many times greater.

Some biologists have extrapolated the current rate of new species being discovered and believe it will level out somewhere between 10 to 30 million species. (An exact number will be impossible until all the experts agree on what constitutes a species—another factor which makes this an extremely daunting task.) But even if every species was interesting enough to describe and name, currently there aren't enough biologists to satisfactorily inventory the diversity that's out there. The field is white for the harvest (of classification), but the laborers are few.

Despite these problems, man has always had an innate desire to classify and systematize everything. This is also true of the mind- boggling diversity of life on earth. It has been done by Adam, Solomon, Aristotle, Pliny, Linnaeus, and other systematists all the way to the present and will continue to be done for years and years.

In fact, one of the first jobs given to Adam was to name all the animals (Gen. 2:19-20). The Bible tells us that he accomplished the task of at least the land animals and birds, but we don't know his language, whether it was written down, or whether there was some kind of classification scheme that accompanied his nomenclature. If he did record it, it was apparently lost or destroyed. Whatever the case, we certainly don't have it now. Nevertheless the job was continued, sometimes by believers, sometimes by pagans.

Let's take a look at some history of classification and the worldviews that have shaped it.

ANCIENT TAXONOMY

The most well-known man among the ancients who attempted to classify living creatures was Aristotle (384-322 BC). He wrote up his work in *Biological Treatises*. It's not a riveting read, but it does reveal just how astute the man was–and how keenly aware of the importance of carefully and thoughtfully selecting his criteria for classification.

PLINY THE ELDER

Pliny the Elder was a Roman natural historian (among other things) in the first century. Late in his life, he wrote *Naturalis Historia*—a massive compilation of the accumulated knowledge in the areas of zoology, botany, geology, mineralogy, and astronomy. He dedicated this 37-volume work to Emperor Titus in 77 AD. How much bigger it may have gotten, we'll never know, for Pliny was killed in the eruption of Mt. Vesuvius.

Figure 15.2 Pliny the Elder

CLASSICAL TAXONOMY

The time period known as "Classical Taxonomy" (so-named by Colin Tudge, a British science writer and biologist) began in the sixteenth century and spanned roughly three centuries, ending with the publication of Darwin's *On the Origin of Species* in 1859. During these three centuries, taxonomy was largely motivated by political, commercial, and economic interests in medicine and horticulture. Scientists developed many keys to help the layperson correctly identify plants (and, to a lesser degree, animals) that were described by taxonomists.

Now, we must also pay attention to the religious context of this period of history. Virtually everyone believed in God as the creator of the world and everything in it. The Christian worldview, in other words, underlay all these taxonomic pursuits. Human intelligence itself was rightly considered to be a gift from the Triune Creator. As the teaching of the 16th-century Reformation spread over Europe, scientific inquiry was more and more accepted

as a noble and reverent act of exploring the mind of God by attempting to unveil the divine order of His creation.

During the Classical Taxonomy period, many taxonomists realized what Aristotle had realized—that they couldn't determine natural categories using animals' general gestalt or other superficial features. So they brought much more detailed biological data to the table: morphology (detailed gross external anatomy and shape), ultrastructure (microscopic features, both internal and external), and embryology (the study of embryo development from zygote to birth or hatching), to name just a few areas.

During the 18th century (the last 100 years or so of the Classical Taxonomy period), there arose from Sweden an amazing naturalist whose work in the classification of life far surpassed the work of all previous taxonomists in history–including Pliny the Elder and Aristotle. His name was Carl von Linne (1707-1778), but everyone knows him by his Latinized name, which he gave himself: **Carolus Linnaeus**.

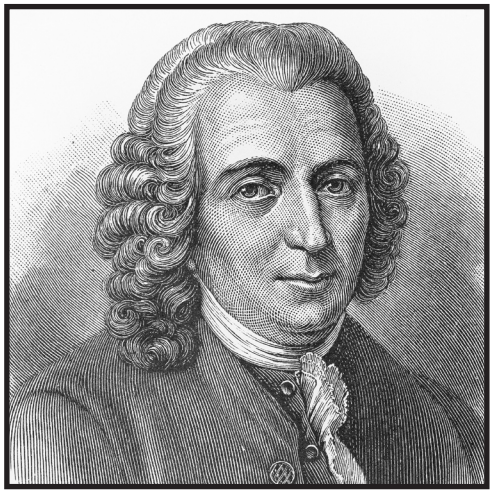

Figure 15.3 Linnaeus

Linnaeus is known as the father of modern taxonomy, and his legacy continues to be as large as it was in his own day. During the mid-18th century, he was the king in all matters taxonomic. Many explorers and collectors sent him new plants and animals for him to describe and name—even species from the colonies in North America.

But Linnaeus also got out of the office and collected things himself. He explored Lapland in 1732 and discovered 100 new plant species. He published his classifications of animals, plants, and minerals in a work called *Systema Naturae* in 1735, though he continued to revise and expand it until the 1750s. In 1753, he also published a work devoted to plants, *Species Plantarum*.

Linnaeus developed the basic hierarchy of classification consisting of five ranks or taxa (singular: taxon) which forms the skeleton of our classification system today:

Kingdom → Class → Order → Genus → Species

We have fleshed it out a bit since then:

Kingdom → Phylum → Class → Order → Family → Genus → Species

We can also thank Linnaeus for the binomial system of naming. Sound complicated? It's far simpler than what he proposed at first: the polynomial system, which consisted of a string of Latin words (no more than 12) that attempted to describe the relevant features of the plant or animal. If he'd stuck with this, just imagine what you could be saying today if you went on a hike and spotted a familiar plant: "Look, Bob, I just found *Nepeta floribus interrupte spicatus pedunculatis*." Linnaeus quickly concluded that this was an unwieldy, impractical way to name and identify a plant, even if you are a Latin geek. He thought it prudent to limit it to just two names (hence, "binomial"—bi is "two" and nomial comes from the word meaning "name"), and we are forever grateful. Now you can just say, "Bob, I found *Nepeta cataria*." (Of course, you can always say "catnip.")

WHY ALL THE LEVELS OF CLASSIFICATION?

It's easy to think that all these layers of name-calling are unnecessary. Are biologists just throwing jargon at us to make the lives of biology students more miserable? No. When we understand the diversity out there, we'll understand that biologists actually have very good reasons for this hierarchy. Let's examine the logic of this system.

The most general taxon is **kingdom**. There are, to date, six kingdoms: Plantae, Animalia, Protista, Fungi, Archaebacteria, and Eubacteria.

For an example, let's look at the kingdom Animalia. Anything that is multicellular and able to move about using some sort of muscular tissue is an animal. This includes a surprising array of critters ranging from sponges, jellyfish, worms, clams, starfish, insects, and all vertebrates. This distinguishes them from all the other kingdoms which do not have these basic traits.

After kingdom, the next taxon is **phylum** (plural: phyla). Among animals it is clear that there are huge groups that can be distinguished from all other animals. For example, the phylum Arthropoda includes all critters with segmented bodies, paired and jointed appendages, and some sort of "suit of armor" called an exoskeleton. This includes crabs, shrimp, spiders, ticks, millipedes, centipedes, and insects. Now, crabs share these characteristics with insects, but they are vastly different creatures, hence the need to split phylum Arthropoda into smaller groups called **classes** (the third taxon). We are all fairly familiar with insects so I will use this enormous group of arthropods as a good example of a class. What distinguishes insects from all other arthropods? The main characteristic is that they are arthropods

with three body regions (head, thorax, and abdomen) and six legs and two pairs of wings (if they have them) protruding from the thorax. Millipedes are in a different class of arthropods because they have gobs of legs with **two pairs sprouting from each segment** (except the first few). Centipedes are in a different class because they have one pair of legs per segment.

But we can't stop at class because if you've seen one insect, you haven't seen them all. So the next taxon is **order**. The class Insecta is pretty darn big, so it has a lot of orders, most of which people are familiar with.

Beetles constitute the order Coleoptera. They are very distinct insects with their fairly thick wing covers (the first pair of wings) spreading over their backs. Beetles are such a vast and diverse order (over 350,000 species)

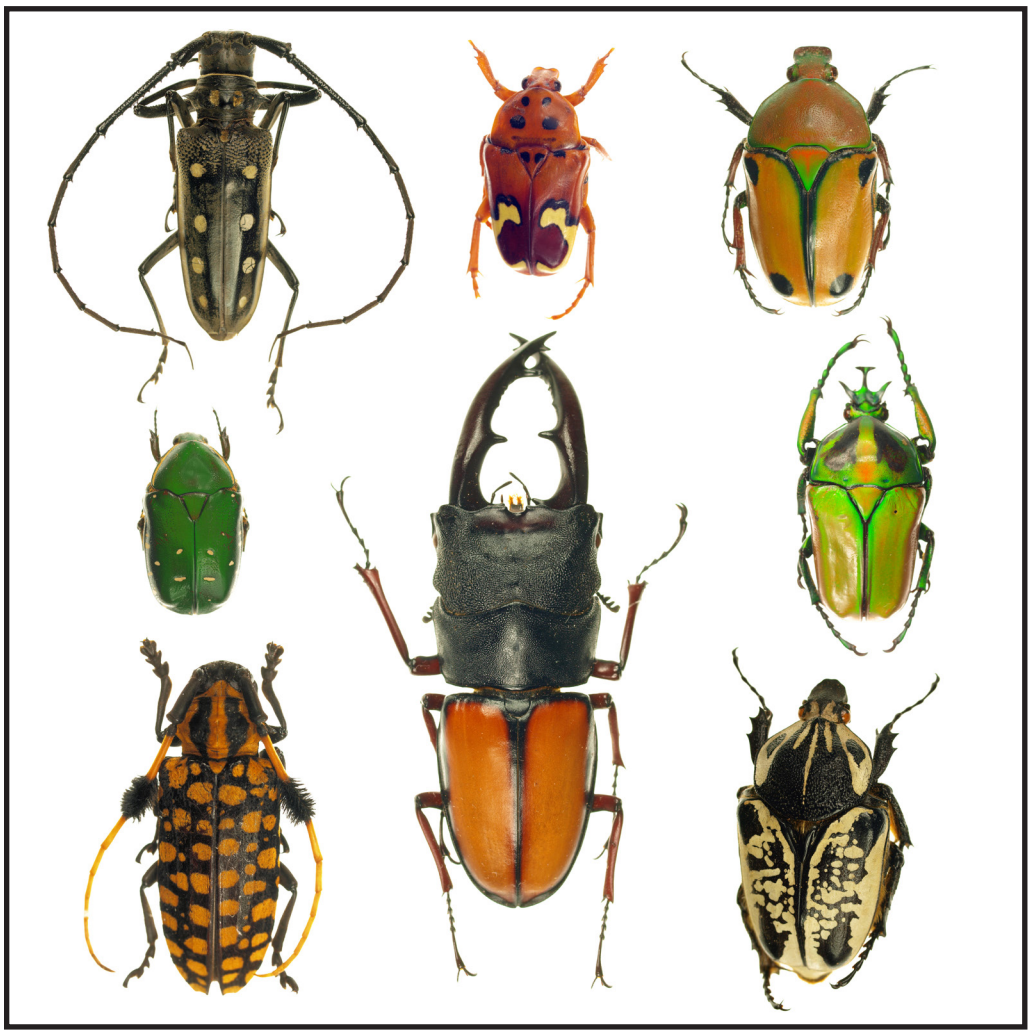

Figure 15.4 Variety of Coleoptera

that it is necessary to break the order Coleoptera even further into **families**.

There are about 160 families of beetles but I will mention just a couple. Ladybugs (properly called ladybird beetles) are in the family Coccinellidae (~400 species in the U.S. and Canada). Weevils (or snout beetles) are in the family Curculionidae (~40,000 species). But we are not done yet. Families are not species. Often families can include tens to hundreds of species. And even among these species, some are more similar to each other than they are to others, which means we need another taxon in between family and species, and that is **genus**. Take weevils, for example.

The boll weevil, *Anthonomus grandis* (pictured to the right), is in the genus *Anthonomus*, but so are the two below, along with many others. . .

Figure 15.5 One of Family Coccinellidae

Figure 15.6 Boll weevil, genus Athonomus

Figure 15.7 Anthonomus rubi *and* Anthonomus rectirostri

RULES OF SCIENTIFIC NAMING

Now that we are down to genus, I can discuss scientific naming. Just so you know, when I say "scientific name," I could also say "Latin name," or "binomial," or "species name." They all refer to the same thing, but I usually prefer the term "scientific name," so that's what we're going to use here.

Okay. Let's discuss the rules of scientific naming. I'm a bit fussy about these rules, so pay attention.

The scientific name consists of two names: the *genus* and the *specific epithet* (the specific epithet is often called "species", but technically that's incorrect because species actually includes the genus name). As mentioned above, the boll weevil's scientific name is *Anthonomus grandis*. *Anthonomus* is the genus name and *grandis* is the specific epithet. Both these names are to be italicized or underlined. This notation demonstrates that it is the proper scientific name and is not to be confused with other higher level taxa such as family, order, etc. The genus (which you *absolutely must include*) is capitalized and the specific epithet is all lower case even if it includes a proper name.

*Figure 15.8 Black Bear (*Ursus americanus*)*

Figure 15.9
*American toad (*Bufo americanus*)*

It is difficult to generate different specific epithets for all 1.4 million species, so specific epithets can be named after a scientist. For example, my major professor, Dr. Carl Ernst has a species of map turtle named after him. The Escambia map turtle, *Graptemys ernsti,* has his last name Latinized as the specific epithet, but it is not capitalized. Specific epithets can also be regional, morphological, or habitat descriptors. Consequently, many unrelated species have the same specific epithet: *Bufo americanus* is the American toad, *Ursus americanus* is the black bear, and *Fraxinus americana* is the white ash.

If I just use *americanus* or *americana*, I'm not telling my reader anything about its actual identity. Is it a toad or a bear or a tree? Many other plants and animals have the same or similar specific epithets, so, like I said, the genus is essential to make a positive ID. After I use the full genus name once, I am free to abbreviate it thereafter, as in *B. americanus*. This is commonly done when the scientific name is a mouthful like *Escherichia coli*. Microbiologists happily shorten it to *E. coli*.

Figure 15.10
*White ash (*Fraxinus americana*)*

WHY USE THE SCIENTIFIC NAME WHEN THE COMMON NAME IS EASIER?

Common names are fine and I use them myself in the appropriate circumstances. If amateur naturalists want to learn the local flora and fauna, they usually want to learn the common names. It's easier and sounds less pretentious.

But when I teach common names, I take special care to make sure it is the *official* common name. The problem with common names is that they aren't universal. The name of a particular species can change from region to region and county to county, and countless trivial disputes can erupt over the name of some critter because everybody learned it differently from their grandpa or farmer Bob down the road.

Most people, not realizing the overwhelming diversity out there try to shoehorn some unknown snake into one of the two kinds of snakes he or she happens to know. I call this widespread tendency the know-it-all syndrome. If a know-it-all knows the names of two kinds of snakes, say, copperhead and garter snake, they seem to think that any serpentine, legless critter must fall into one of those two categories. It's like putting an unknown-shaped peg into one of the two unknown-shaped holes you have in your head. Somehow, knowing nothing is strangely conflated with knowing everything.

Now, some people are refreshingly discriminating and are very certain that this particular critter is in fact what they learned from their Grandpa. And they are correct. The problem is not that they are being careless

with the knowledge handed down from their grandpa. The problem is their grandpa was wrong.

To silence these petty disputes, just consult a field guide. Or an expert, if you have one of those with you. They also provide the 'official' common names. But I digress. Back to scientific names.

Scientific names are universal ID cards that don't change whether you are in the U.S. or France or Japan. The scientific name of the common box turtle is *Terrapene carolina,* period. If a French biologist decided to study it and write a scientific technical paper in French, the name would appear the same: *Terrapene carolina*. This convention is exceedingly useful because it provides a standardized name under which all scientific information (amassed from scientists past and present from all over the world) can be stored. Knowing the correct name means that I can now access all that information (international in scope) about a particular creature. It might take some work and I might need a translator if it is written in a different language, but I at least have access to it.

Figure 15.11 Western fence lizard

An official common name may also give me ready access to the same information. The western fence lizard (official common name) is *Sceloporus occidentalis,* but is also called the blue-belly and fence swift. If I were searching for accurate scientific information on this lizard, my best bet would be to use either the scientific name or the official common name. If I used the names "blue-belly" or "fence swift," my search would be slower or even altogether futile because both these names can have different meanings, refer to different species altogether, or lead me to unscientific or unreliable sources of the correct species. In short, they all lead me down rabbit trails that hamper an efficient search for reliable information.

Again, the benefit of a standardized scientific name for each species is that it provides a universal label under which all biological data can be stored. This data can then be retrieved by scientists and naturalists worldwide.

SO WHAT'S A SPECIES?

There are many definitions of species and many controversies as to what constitutes a species, but I will give you the one that seems to hold the most sway among most biologists. The definition of **species**:

> a group of organisms that resemble each other quite closely and can potentially, freely, and naturally interbreed producing fertile offspring and do not normally interbreed successfully with other such groups.

Every single word in that definition is vital. Let me comment on a few words and phrases in particular.

"Do not normally interbreed successfully with other such groups." Often, two species can look almost identical but aren't considered the same because they do not freely interbreed at all, or if they do, they don't produce fertile offspring. On the other hand, individuals in the same species can appear quite different physically but freely and naturally interbreed producing fertile offspring. Yes, two similar species may mate in artificial conditions or in a rare union in nature and still produce fertile offspring, but since it doesn't occur naturally or frequently, the two are still considered separate species.

Figure 15.12 Eastern box turtle

In the definition, "potentially" refers to the fact that the males and females would readily mate and produce fertile offspring, if location details were worked out.

Figure 15.13 Florida box turtle

WHAT'S A SUBSPECIES?

It's a subset of a species with one or more shared physical features that are not present in the other subspecies.

In Figures 15.12–15, you see a favorite example of mine—the box turtle (*Terrapene carolina*). Here's a list of four subspecies. The third name is the subspecific epithet.

Eastern box turtle (*Terrapene carolina carolina*)
Florida box turtle (*Terrapene carolina bauri*)
Gulf coast box turtle (*Terrapene carolina major*)
Three-toed box turtle (*Terrapene carolina triunguis*)

Figure 15.14 Gulf Coast box turtle

MODERN TAXONOMY: HOW THE THEORY OF EVOLUTION IMPACTED TAXONOMY

Almost the entire scientific community is under the influence of Darwin's revolutionary book, *On the Origin of Species*. After the book gained greater and greater acceptance in the scientific community, taxonomists began to construct classification schemes which attempted to trace the supposed evolutionary history (phylogeny) of all life from a common ancestor, and to reveal evolutionary relationships in the family tree of life (systematics).

Figure 15.15 Three-toed box turtle

Now, what's curious to note is that much of Linnaeus's classification did not change. Linnaeus is still greatly respected in taxonomy. His classification schemes have, in principle, remained largely the same. (Things are often reclassified based on new data. Also, new taxa are added to reveal more levels of similarity or dissimilarity.) This is strange because Linnaeus was a *creationist*. How could evolutionary biology build upon the work of a creationist?

This is because when classifying creatures, creationists and evolutionists analyze the same morphological, anatomical, embryological, and biochemical data. If both types of people are intelligent, logical, and observant, they

can wind up grouping creatures in very similar patterns and hierarchies. The radical differences are not so much in how they *group* organisms but in how they *interpret* these groupings.

A good way to visually explain the different interpretations is to show you the Linnaean Lawn, the Evolutionary Tree, and the Creationist Orchard. This helps you see how three views of life's history can be very different from each other, and yet classify life in the same or similar ways.

THE LINNAEAN LAWN

Figure 15.16 represents how pre-Darwinian biologists viewed life. Each vertical line represents a species. The top of each line is a species today and the bottom represents its creation. Lines close together represent species that were created according to a similar pattern.

Note that the lines do *not* merge into a common ancestor in the past. Linnaeus was a gifted taxonomist and was fully aware of strong resemblances between certain species; he even classified the orangutan in the same genus (*Homo*) as humans and named it *Homo troglodytes*. Ironically, although he classified it even closer to humans than evolutionists do today (in the same genus), he did not consider it to *share* a common ancestor with us. Evolutionists, on the other hand, classify the orangutan in a different genus and yet believe we share a common ancestor. All this shows that the *logic* we use in grouping doesn't necessarily differ. What differs is the *reason* for the similarity.

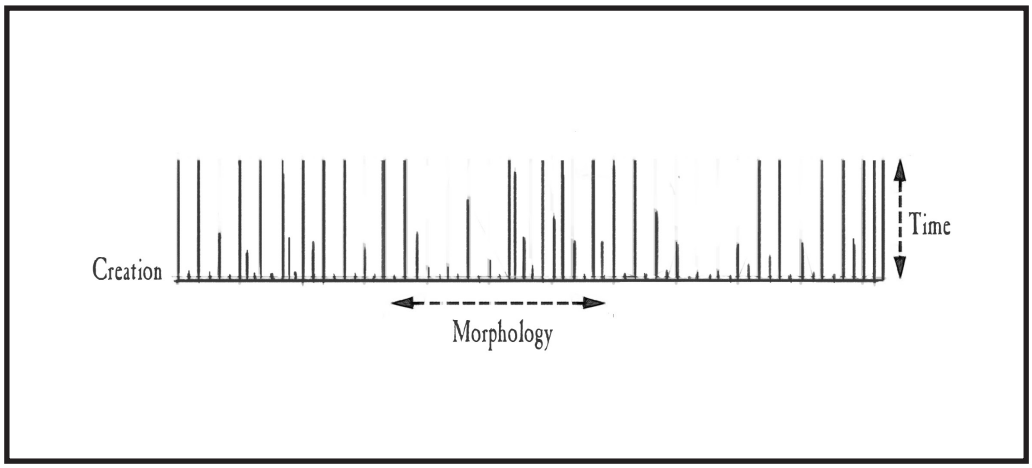

Figure 15.16 The Linnaean Lawn

THE EVOLUTIONARY TREE

With the advent of evolutionary thinking, scientists thought that similar species were similar because they shared a relatively recent ancestor. Instead of blades of grass in a lawn (each separate and distinct), the extant species were twigs on a tree—each of them connected to the others if you traced it back far enough. As you go back in the past, the twigs merge into small branches, small branches merge into bigger branches, and so on down to one trunk. (Like a massive family tree.) In Linnaean classification, a small branch bearing a few twigs would represent a genus. A larger branch bearing a few smaller branches would represent a family, and so on.

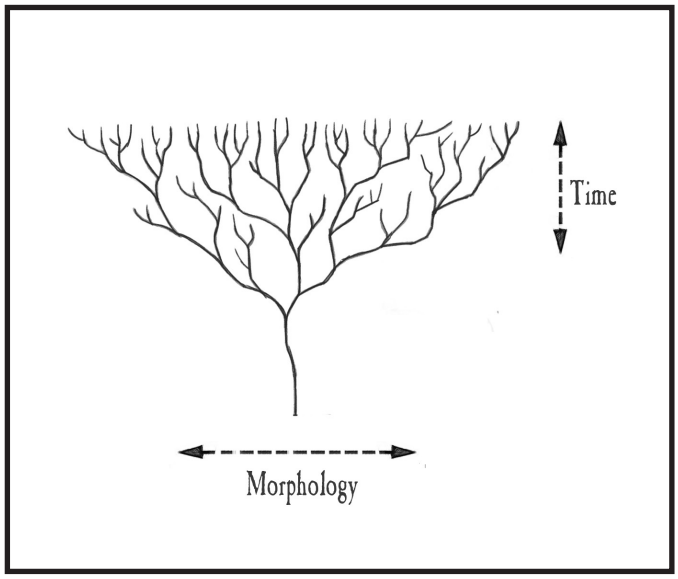

Figure 15.17 The Evolutionary Tree

THE CREATIONIST ORCHARD

Creationists understand that species exhibit *limited* change over time. This change does not exhibit any increase in complexity or net gains in genetic information; it simply means that God created the various kinds with genetic breadth and versatility to adapt to an ever-changing environment. These created kinds (also known as **baramins**, from the Hebrew words, *bara,* "to create" and *min,* "kind") had the innate capacity to diversify (or split) into a number of similar species. These baramins may correspond to certain taxa known today, such as genus or even family.

This is not compromising Scripture or cowing to the evolutionary worldview. The Bible says God created plants and animals "according to their *kind*," not according to their s*pecies*. Unfortunately, in the history of the church, "kind" was conflated with "species." This position is not only unbiblical, it is also indefensible against scientific evidence for the mutability of species.

In Figure 15.18, each tree in this orchard represents a baramin (a created kind). The branching indicates that each kind could give rise to a number of species. For example, the dog family is a baramin and includes wolves, coyotes, jackals, foxes, and domesticated dogs.

Baraminology is an interdisciplinary study which attempts to figure out the boundaries of each created kind. Data from genetics, hybridization studies, biochemistry, biogeography, morphology, and paleontology can be analyzed to try to figure out a particular baramin.

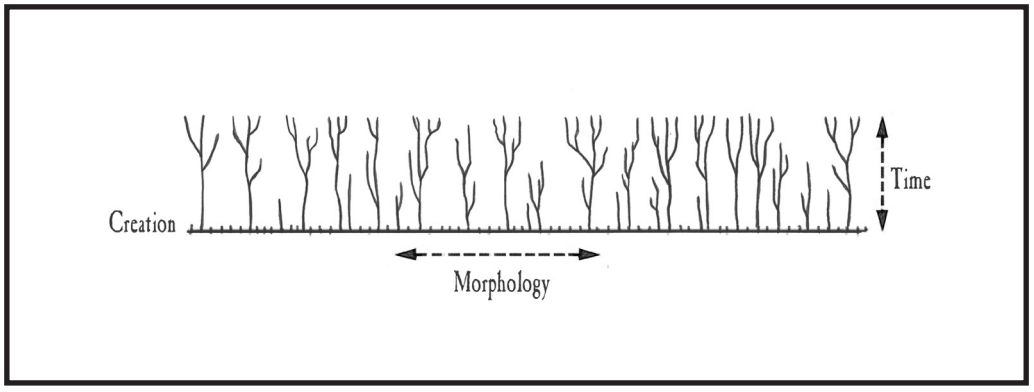

Figure 15.18 The Creationist Orchard

MODERN TAXONOMY THROUGH EVOLUTIONARY EYES

There are several schools of thought regarding classification. **Cladistics** (from the Greek word *klados* meaning "branch") is the dominant method of classification that attempts to classify organisms based on their evolutionary ancestry. This word for branch refers to the branching nature of the evolutionary tree.

The branching pattern, since it is based on certain assumptions about who evolved from whom, is greatly affected by what characteristics are chosen to work out the tree. Cladistics relies heavily on DNA and RNA sequences because DNA and RNA are the stuff of inheritance, but it uses morphological data as well.

Although the technology involved in drawing such a complicated tree is impressive, the Cladist is still beset with a similar problem to the one Aristotle had: which characteristics are the most important in determining who is related to whom?

TERMINOLOGY OF CLADISTICS

To best understand all the terms used in cladistics, let's get inside the head of an evolutionist (just this once) and assume that all creatures evolved from a common ancestor. This is not an evil exercise. Remember, the best way to destroy your enemy's worldview is to know it and be able to think within it. When you know the details of Darwinism, its weaknesses are much more apparent.

Homologous structures are anatomical features which organisms share because they inherited the basic structure from a common ancestor. One common example of a homologous structure is the pentadactylous (five-fingered) forelimb. The science-fiction story of evolution tells us that descendants split into a number of different groups which then adapted to different habitats through variation and natural selection. Consequently, this five-fingered forelimb was molded into a variety of different functions, such as grasping (in humans); walking, running, climbing, catching prey (in cats); swimming (in whales); and flying (in bats). When this occurs during evolution, the structure is said to have undergone **divergence**.

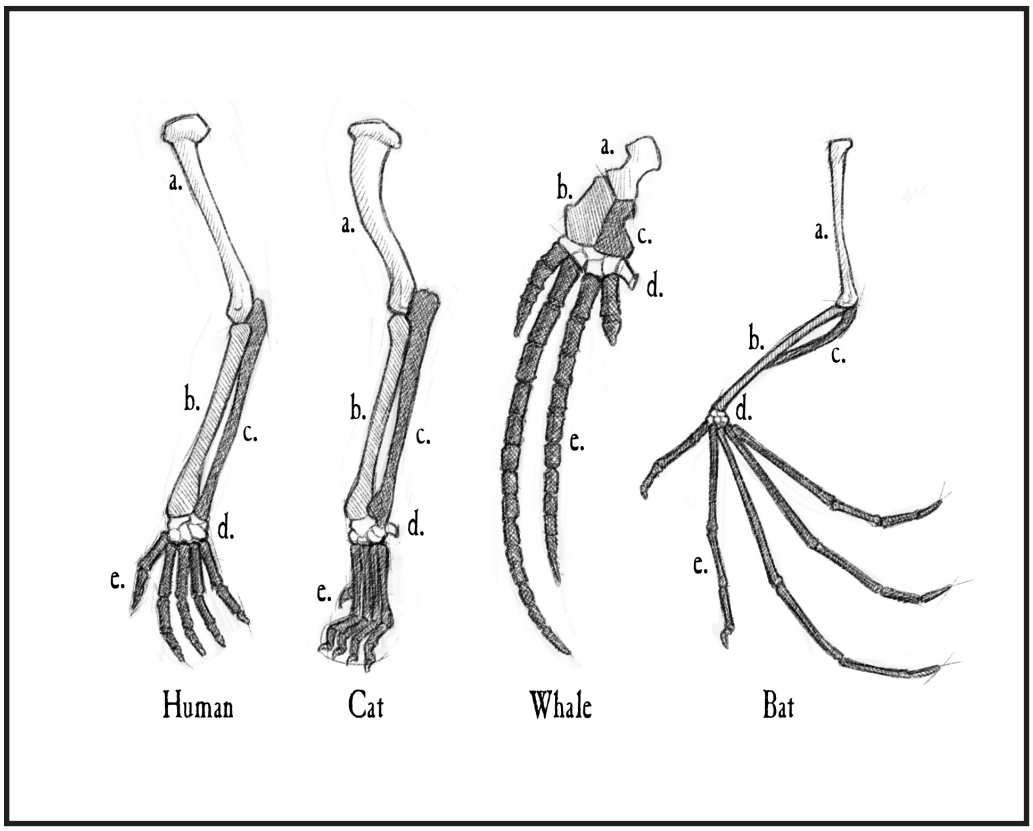

Figure 15.19 Homologous front limbs

Though the limb is used differently by various groups, it is considered "homologous" because it appears to be very structurally similar. For instance, all the above forelimbs have an internal bony skeleton composed of the humerus, radius, ulna, carpals, metacarpals, and phalanges. From an evolutionary perspective, the only sensible reason they would be so similar structurally is that they inherited this basic limb from some common ancestor, like a pre-dinosaur reptile. From a creationist perspective, the similarities are due to a common design from a common Creator. Only if the creatures belonged in the same baramin would they actually be homologous structures.

Analogous structures are anatomical features that have the same basic function but were not derived from the same *structure* in the common ancestor.

A typical example of this is the wing of a butterfly and the wing of a bird.

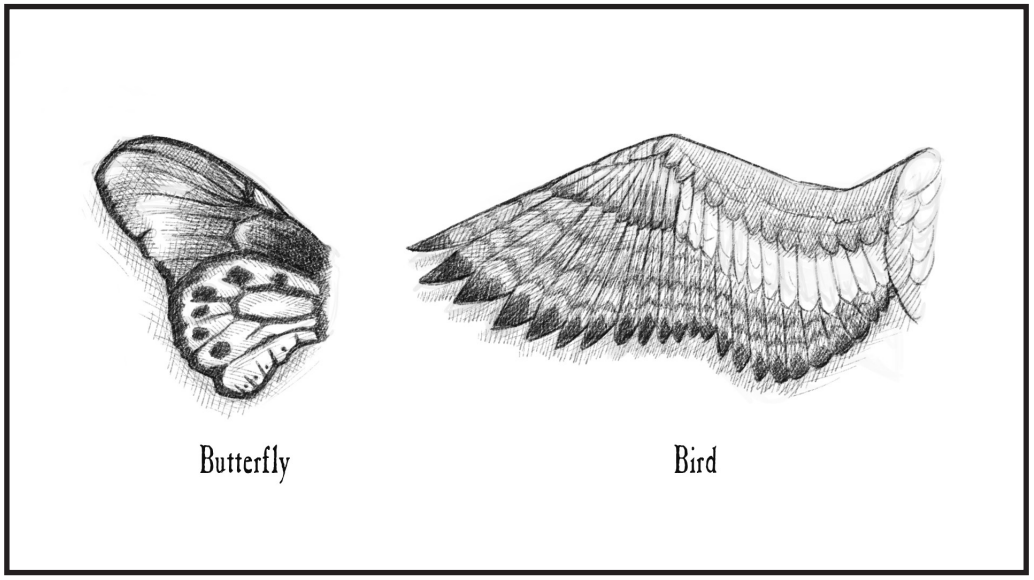

Figure 15.20 Analagous wings

Although evolutionists believe insects and birds have a common ancestor somewhere way back in time, it was long before insects or birds had even become insects and birds, so of course their wings were not on the scene. Insect wings and bird wings thus evolved independently of each other, hundreds of millions of years *after* their wingless lineages split from one another. Their wings are analogous because they have a common *function* (flying), but they actually evolved from different parts of their bodies and developed in completely different ways. When totally different structures in

totally different bodies evolve similar functions, it is said (by evolutionists) that they have "converged" or they have "undergone **convergence**."

A **clade** is a group of organisms: the ancestor and all of its descendants together. A diagrammatic representation of one or more clades is a **cladogram**. The branching pattern is usually two-way. Below is a simple cladogram of a few vertebrates.

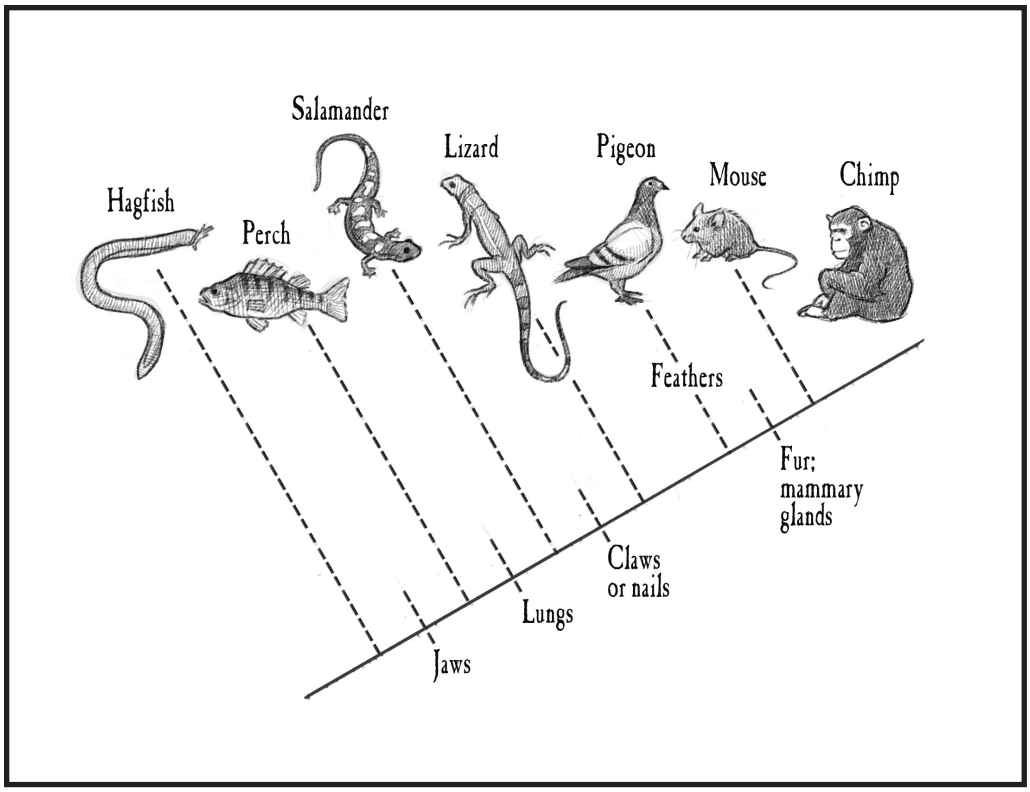

Figure 15.21 Cladogram of an array of vertebrates

SOME MORE TERMS

These may seem like meaningless details, but trust me—they're important. So we're going to go over a few more terms that really help to clarify where evolutionists and creationists part company. You should be thankful that this is barebones cladistics. It could get a lot more complicated.

A **monophyletic** group is a clade. For example, we have both biblical and scientific evidence that all the humans (from Adam and Eve on down), form one clade. Therefore, humans are a monophyletic group.

A **paraphyletic** group is simply a subset of a monophyletic group. A branch or two of a clade of interest is chopped off and excluded. For example, using

cladistic logic, if I were to consider the reptile clade (the first reptile and all of its descendants) I would be dealing with way more than reptiles. According to evolution, birds evolved from reptiles, so technically-speaking, birds are in the reptile clade. However, most herpetologists don't let cladistic logic force them to include birds in a herpetology course. They simply exclude birds for several practical reasons (one of which is that they know precious little about birds).

In the cladogram below, the monophyletic reptile clade is highlighted in cream. The paraphyletic group that we call reptiles (excluding birds) is highlighted in blue. A **polyphyletic** group consists of portions of two or more clades, but does not include many of the ancestors that would unite them all into a single clade.

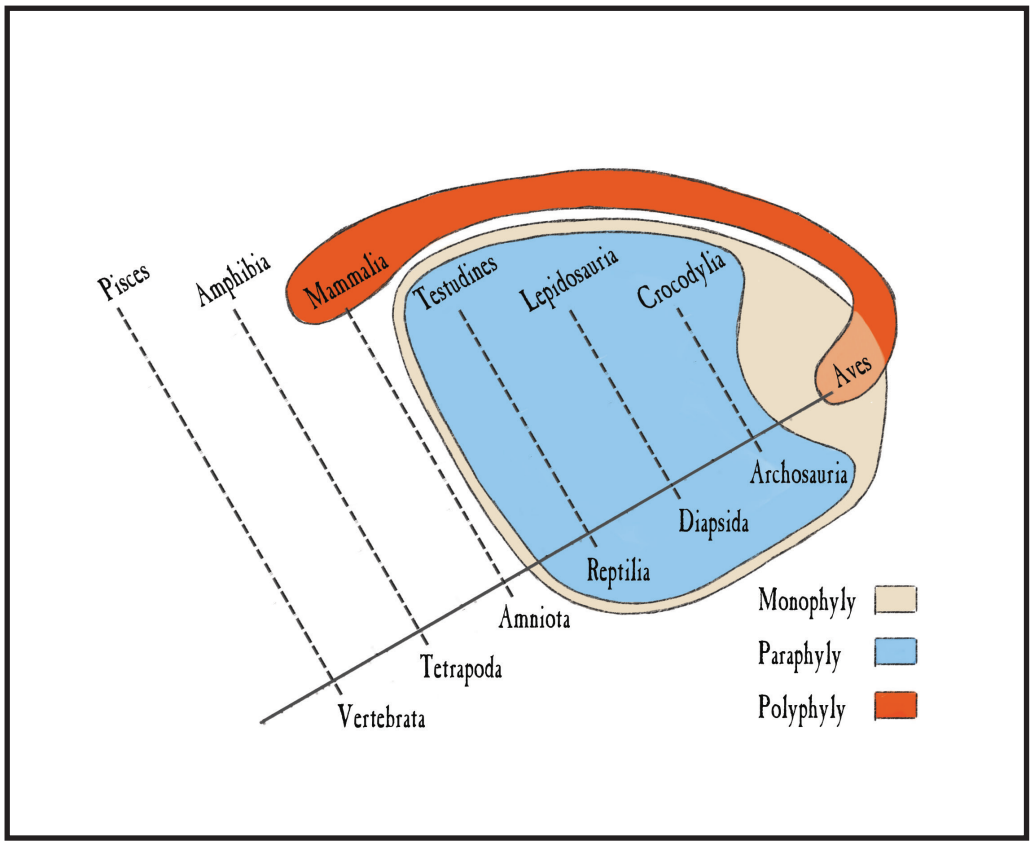

Figure 15.22 Cladogram: Mono-, para-, and polyphyletic groups

For example, endotherms (warm-blooded vertebrates) would be polyphyletic (red) because they would consist of birds and mammals, but would exclude all the cold-blooded ancestors that would unite them all into one big happy clade.

As in the reptile example, cladistic logic often leads to ridiculous clades. According to evolution, everything evolved from bacteria in the primordial soup 3.5–3.8 billion years ago. Consequently, the bacterial clade (ancestor and all descendants) includes the ludicrous assemblage of bacteria, beech trees, boletes, bivalves, bumblebees, bass, bullfrogs, bearded dragons, baleen whales, and ballerinas. Give me a break.

These two terms, "monophyletic group" and "paraphyletic group," are crucial in understanding the fundamental problem with evolutionary thinking. If we creationists believe in a little bit of branching within one baramin (within a tree in the creationist orchard), then why do we have a problem with branching that unites the whole tree? The problem is revealed with the term apomorphy (or derived character). An **apomorphy** is a completely new or novel structure that somehow evolved from scratch within a population of creatures. This structure sets it apart not just as a new species that can no longer interbreed with a sister species, but as something totally new, apart from its own ancestors. The ancestor does not have the structure or the genetic information to code for it.

One good example of an apomorphy is the feather. Before feathers ever existed, some kind of featherless dinosaur had to mutate in a way that bestowed his offspring with the ability to grow feathers (of some sort) out of its skin in addition to its scales, of course. The theoretical problem here is that the information for feather structure and assembly is an exceedingly complex genetic recipe. And these complex instructions are presumed to have magically arisen from random mutations in extra copies of "scale" genes in the featherless dinosaurian ancestor of birds. But feathers are simply too complicated to have sprung from genetic typos in the DNA coding for scales. This kind of change is not the modification of an existing genetic recipe; it is a completely new recipe.

You see, this is the big difference between microevolution (modifications within a baramin) and macroevolution (evolution of apomorphies): the former is testable and observable, while the latter has never been observed nor does it even make sense theoretically.

If one considers the entire evolutionary tree, there are countless examples of organisms with apomorphies (completely new stuff) that had to arise from critters without them: teeth, turtle shells, mammary glands, antlers, scales, fur, hair—I could go on all day. There is no *empirical evidence* for this kind of addition. Yes, it's possible for ancestors to produce offspring with *slight* modifications to existing anatomical stuff (modifications within a baramin),

but new stuff from scratch without a Craftsman? Both Scripture and the scientific evidence clearly say "no."

A **plesiomorphy** (or an ancestral character) is a structure already present in the ancestor of a particular clade. In the simple clade of vertebrates shown earlier (Figure 15.21), the ancestor and all its descendants have the vertebral column (that's why they're all vertebrates), which would be the plesiomorphy of this clade. However, you also see a number of apomorphies (hash marks along the right-handed branch) that appear in various points during vertebrate evolution. These include jaws, lungs, claws or nails, feathers, and fur/mammary glands. I should point out that an apomorphy in a larger clade can be considered a plesiomorphy of a smaller clade. For example, as mentioned before, feathers are an apomorphy in vertebrate evolution (starting at jawless fishes). But if we examine the bird clade alone, feathers can be considered a plesiomorphy of birds.

An example of an apomorphy in the bird clade would be the specialized super-extendable and barbed tongue of the woodpecker family. Not all

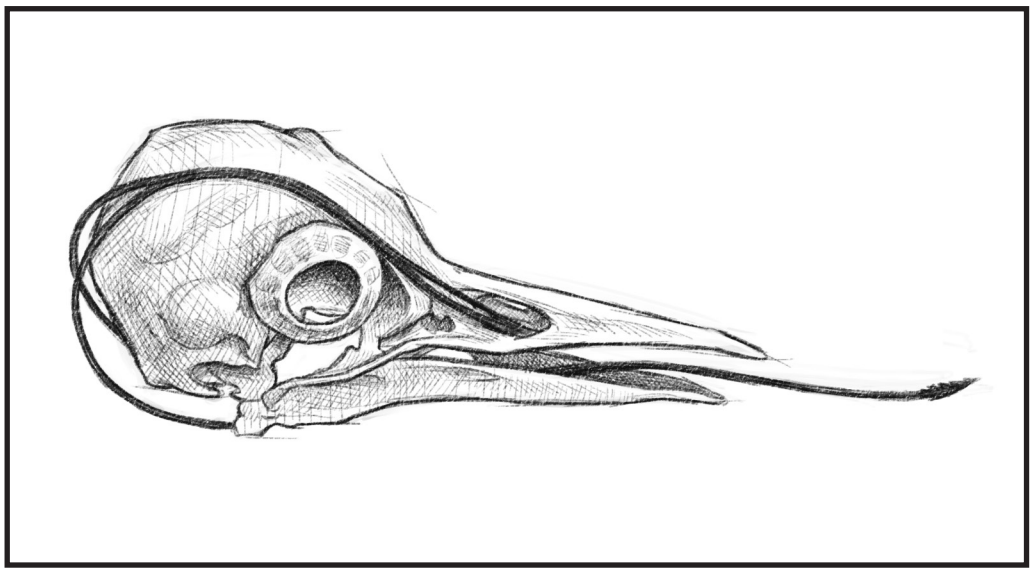

Figure 15.23 Woodpecker's tongue

birds share this feature, and according to evolution, it evolved as a new innovation in this family. Some might argue that the tongue is a plesiomorphy possessed by all birds and the woodpeckers just modified it in a unique way. However, the woodpecker tongue is very unique in structure, arrangement, attachment, mechanics, and development. Many of these features would not be present in an ancestral bird tongue and therefore should be considered an apomorphy.

Well, that wraps up the introduction to classification. Now we will plunge into an overview of God's incredible array of creatures spanning the six kingdoms.

The two bacterial kingdoms will be discussed only broadly at the kingdom level. Most of this overview will include a basic natural history of the viruses, the prokaryotes, and the four eukaryotic kingdoms.

The eukaryotic kingdoms will be treated with more depth and I will cover their major phyla and classes. **Natural history** typically refers to and includes important aspects of physiology (function), morphology (structure), and/or behavior in its natural habitat. Its approach is more observational and descriptive rather than experimental. **Ecology** is also the study of creatures in their natural habitat and is often used interchangeably with natural history, however, it tends to have a more scientifically rigorous, experimental, and quantitative approach compared to 'natural history.' Other ecological relationships such as symbiosis (predator-prey, parasitism, commensalism, and mutualism) and competition will be discussed when good examples arise during the survey. Homeostasis, which is how organisms respond to a fluctuating environment to stay alive, will also be discussed using a variety of examples. For some of the larger or more conspicuous classes, I will even dip down to the order level. I will make every effort to reveal aspects of creatures that are the most representative and/or awe-inspiring.

CHAPTER 15: REVIEW QUESTIONS

1. One of the first taxonomists of the fourth century B.C. was _____.

2. Different classification schemes result from differences of opinion on what _____ are the most important to compare or contrast.

3. A Swedish naturalist named _____ was the father of modern taxonomy. He proposed the _____ system of naming that is still used today.

4. What are the seven ranks (taxa) in the classification hierarchy that Linnaeus developed (although it has been added to)? Go from general to specific.

5. Similar families are grouped into a single_____.

6. A class is split into several_____.

7. What are three synonyms for the binomial?

8. The binomial of the American toad is BUFO AMERICANUS. Rewrite it correctly.

9. What is its genus name? Species name? Specific epithet?

10. Name three ways to visually represent biological diversity according to worldview?

11. Which one above represents fixity of species?

12. From an evolutionary perspective, butterfly wings and bat wings would be considered _____ structures because they didn't evolve from the same feature in their common ancestor.

13. From an evolutionary perspective, front flippers in dolphins and human arms would be considered _____ structures because they did evolve from the same feature in their common ancestor.

14. From an evolutionary perspective, the evolution of a totally new anatomical feature (a derived character) is considered a(n) _____.

15. From an evolutionary perspective, a feature that both ancestor and descendents possess is called a _____.

16. A group of organisms which includes the ancestor and all of its descendents (monophyletic) is called a _____.

17. From an evolutionary perspective, birds are a part of the _____ clade.

18. If birds are excluded from the reptile clade for practical reasons, the remaining reptile group is termed _____.

19. If a two or more clades are lumped into one group because they share a common feature but the grouping excludes the common ancestor and other members that would unite them into a single clade, it is termed _____.

20. Pick one: Creationists object to evolution when it involves the A) Minor modification of a plesiomorphy, or B) Addition of an apomorphy.

CHAPTER 16

THE VIRUSES AND PROKARYOTES

Microbiology is a vast field of study that studies life at the microscopic scale. It can include viruses, bacteria, protists, fungi, as well as aspects of plants and animals that are studied at the molecular and microscopic level.

VIRUSES

Virology is the subset of microbiology that focuses on viruses. Viruses are interesting because they straddle the border between life and non-life. They contain some features of living things, (such as protein and nucleic acids), but they don't really *live* in the normal sense. They don't carry out metabolic processes independently. Outside a host cell, they can't eat, grow, or reproduce. They are like little genetic software packages; they literally have to get their DNA or RNA inside a host cell to sabotage it. They take control of the host's metabolic machinery to transcribe viral DNA and make viral proteins. They even use the energy of the host cell to do their dirty work. The host cell is basically converted into a factory to make more viruses. Eventually, this hijacked cell bursts, releasing many freshly minted viruses.

Thousands of different types of viruses infect cells of bacteria, protists, fungi, animals, and plants, and cause a whole host of diseases with a mind-boggling array of symptoms ranging from barely noticeable to lethal.

Needless to say, viruses are tiny even compared to cells. They consist of a protein coat called a **capsid**. The capsid serves as a container of the virus's genetic information (either DNA or RNA.)

Figure 16.1 is a diagram of a virus called a **bacteriophage** infecting a bacterium (yes, even bacteria get sick and die) and doing its mischief.

Infecting a single cell is pretty straightforward, but with more complex multicellular hosts the viruses generally need to gain access to the interior where they can find vulnerable cells into which they can inject their genetic