

Surviving The Cyber Age

Chapter 7 – Transportation, Manufacturing, and Infrastructures

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The big picture

Before we start down the path, it's worth noting that we exist in an infrastructure we call the Universe. It provides the context of cybernetic systems by virtue of its nature, the description, analysis, and study of which we might reasonably call 'physics'. The folks who talk about the "multiverse", in my view, don't get it. If there are multiple realities, they are all part of the one "Universe" (from the Latin *Unis* [One] *Versus* [Turned] meaning "all things turned into one" or alternatively "everything as a whole"). This infrastructure as it exists (assuming it does and we do – "I think therefore I am")¹ is the context in which we came to be.

We see evidence of the formation of the Earth rotating around the Sun, rotating around the center of the Milky Way Galaxy, spreading out from the center of the 'known universe' and leaving in its wake while adding to it over time through meteors and interstellar transport, a planet we live on. This planet has on and near its surface, a wide range of emerged and emerging cybernetic systems. The infrastructure of the Universe has transported and assembled (i.e., manufactured) the components and the whole of the composite planet Earth.

The triad of transportation, manufacturing, and infrastructure

Communication and transportation are closely linked in a number of ways, but I will focus for now on transmission. **Transportation** is just about movement of things. But if the things being moved are informational, transportation provides a means for transmission of content via physical movement. So transmission as communication via transportation. Then we have communication as transmission coded as waveforms like light and sound in a media. Then we have communication in documentary form as opposed to oral or visual signaling that remains present after transmission is started. Then we have transmission as physical movement of documents or transmission in documentary form via wave forms as communications. In the information age, we increasingly replaced transportation with communication for transmission of information and documentary forms. So today we still have all of these intermixes of transportation, transmission, and communication. And then there is transmission over time.

For the fun of it, the fastest way to transmit 400 Tbytes of information between computers on Earth remains physical transportation of the disks it takes to store it, while the fastest way to transmit disease information within a body remains encoding it in molecular form and sending it through blood. Manufacturing and transportation as transmission. Now some details.

Manufacture is defined variously as "make something on a large scale" and similar things², so manufacturing is an act of making things. Physics says you cannot create something from nothing, so it involves making some thing(s) into some other thing(s). I will take large scale to

1 Descartes Latin: "*Cogito, ergo sum*"

2 Some other definitions include: "something made from raw materials by hand or by machinery" and "the act or process of producing something", and others

imply repeatedly using similar processes and mechanisms and in indefinite quantity. While most people probably think of this as mechanical processes, definitions even in dictionaries cite things like “*The manufacture of blood goes on constantly in the human body.*”³

Infrastructure is trickier. I like this definition a bit: “*the underlying foundation or basic framework (as of a system or organization)*”⁴ Here’s a slightly different one: “*the basic foundation or underlying framework of an organization or system*” It forms a context within which other things can happen. But I really mean something physical, not a philosophical perspective, at least for the purposes of this chapter. I reserve the right to change my mind (the infrastructure) later...

Coevolution of transportation, manufacturing, and infrastructures

As we work our way up the transportation stack from physics through modern transportation systems, there is a coevolution of transportation with manufacturing that ultimately leads to infrastructures. For some initial clarity before diving into the specifics, transportation mechanisms require some sort of reproduced ability to make or gather whatever is being transported. Reproduction is a manufacturing process that takes raw materials, expends energy, and manufactures a possibly evolved version of the source entity. Whether we are discussing computer viruses, biological viruses and cells, or any other sort of living thing, there has to be a reproductive mechanism in order to produce more than one of anything. In volume, we can understand the complex environments that support life as infrastructures, within the bodies of complex life forms as well as in their environments.

Coevolution is the way we discuss the interactions that lead to specialization over generations of these mechanisms to interact with each other and succeed in the sense of survival of the multiple interdependent species that form the living environment in which we operate. For clarity, reproduction in this sense is not independent of the environment, but rather the environment is the substrate within which any creature survives (or doesn’t). Every living system, and every cybernetic system whether living or not, exists and operates only within the environments that allow it to operate. Without the environment, the operational mechanisms cannot work, and the environment is in substantial part a result of the operation of the cybernetic mechanisms within it.

As the environment enables the cybernetic systems to form and reproduce through the conditions it puts in place, the cybernetic systems produce environmental changes through consumption of resources and production of products and byproducts, changing conditions of the environment that then enable some and disable other cybernetic mechanisms, and so the cycle continues to the coevolution of the ecosystem as a whole. While we don’t necessarily think of it this way most of the time, everything we create is created in the context of the environment in place, and everything we do effects the environment over time. The inherent limitations discussed earlier apply to every component of every composite, every composite formed by these components, and the composite of all the components that form our world.

These reproductive processes are all cybernetic manufacturing processes, and as they come in volume, infrastructures form within complex life forms. The internal infrastructures include things like fluidic systems that move nutrients from place to place within the bodies of

3 <https://www.merriam-webster.com/dictionary/manufacture>

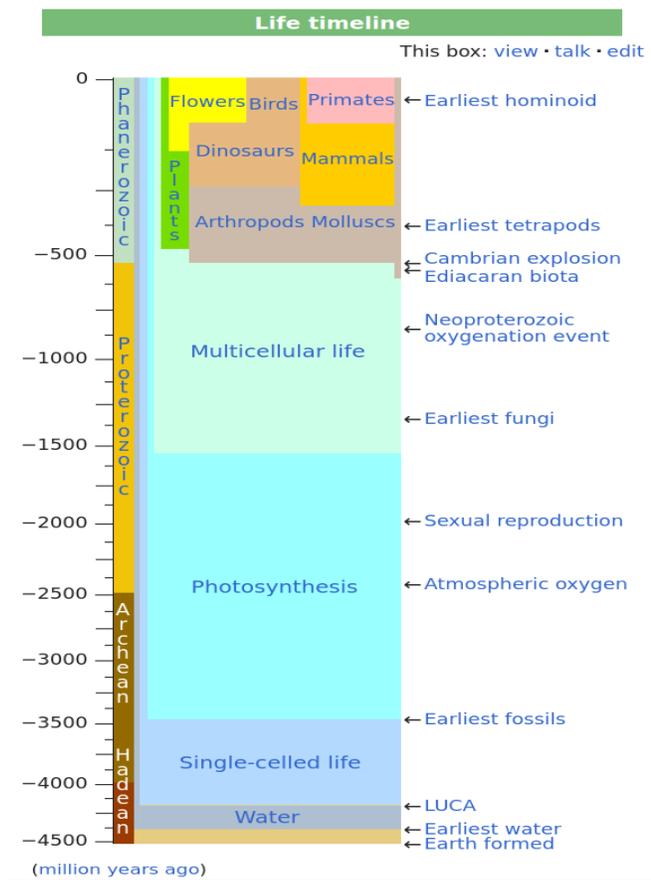
4 <https://www.merriam-webster.com/dictionary/infrastructure>

complex life forms, digestive systems that break down ingested raw materials into components that internal manufacturing systems in internal organs turn into components of the composite that are then transported to become integrated into the composite. There are information infrastructures that provide the sensors, actuators, communications, and control elements that control movements and stimulus response mechanisms.

Between these complex life forms they also build infrastructures in the environment as they become mechanisms that produce waste that is consumed by other creatures for their survival as part of their co-evolved environment. Human waste is food for creatures that consume it for their survival, and their waste for other species, and so forth. It is not recursive ad-infinitum, but rather a finite regress to the physics level, and one that we may one day more fully understand as a species, if we keep seeking to do so.

Movement vs. Transportation

We have discussed movement to an extent in the previous chapters, and mentioned things like ambulances and vehicles, but it's time to start to look more seriously into transportation. The difference between movement and transportation is that transportation involves movement of things beside the vehicle itself. If a portion of a cell moves to perform steps in reproduction, that's different from the fact that parts of the cell actively transport (move other things around) components used in its manufacturing of composites for its reproduction. In



the same way, communication typically doesn't count on moving individual atoms from source to destination, but rather, on generating waves in the media that the media 'carries' from place to place. In transportation we aren't talking about transmitting waveforms, but rather moving the media itself, or moving other things through media to other places.

Having said that, transportation within and between components is used to create movement of composites, which may be components of larger composites that transport things at the component level for movement of the higher level composite. Generally, any manufacturing process will likely involve movement of mechanisms of the manufacturing mechanism and transportation of the mechanism or of the components it breaks down and reassembles. To the extent these manufacturing and transportation mechanisms are not purely random, they necessarily involve some sort of control system.

Time scales

Time in the history of Earth is broken down by those who study it into different periods for the purposes of understanding various issues in environment, life forms, geology, etc.⁵ There have been many mass extinctions and diversifications after those extinctions as biological systems evolved over time. For reference, periods discussed here are predominantly characterized per the diagram at left.⁶

For understanding cybernetic systems prior to humans, and in particular for dealing with the past and future issues regarding transportation, manufacturing, and infrastructure, discussion starts with a drill-down into these time frames and the conditions (infrastructures) they occurred in, the changes they produced (manufactured), and location as it changed over time for life forms (transportation). In the big picture of surviving the cyber age, the story of survival over the ages starts to make sense in terms of what we face.

In the beginning, ...⁷ the heaven[s] and the Earth. The details provided are divided into ranges of time in millions of years ago (Mya).

Appendix A goes into details on these aspects of evolution, including the conditions (infrastructure), manufacturing processes of cybernetic systems and the changes in infrastructure they produced or helped to produce, and the transportation systems that moved them around the world. But for now, we will focus on examining this from the dimension of lowest level mechanisms to highest level mechanisms up to but not including hominids.

The physics level

At the physics level, gravity attracts mass causing movement through space. But electrical charges also attract unlike and repel like particles, and the effect of these forces produce movements in other things bound to the things being moved. Neutrons have no electrical charge, and yet the atoms they form part of the nucleus of are moved around by other forces, so the neutrons are transported as passengers on the travels of the atom as a whole.

There are two other forces at the sub-atomic level: strong, and weak, and all matter is formed from two building blocks, quarks and leptons, according to current scientific understanding.⁸

“Gravity and electromagnetism are well known at the macroscopic level. The other two forces act only on subatomic scales, indeed on subnuclear scales. The strong force binds quarks together within protons, neutrons, and other subatomic particles. Rather as the electromagnetic force is ultimately responsible for holding bulk matter together, so the strong force also keeps protons and neutrons together within atomic nuclei. Unlike the strong force, which acts only between quarks, the weak force acts on both quarks and leptons. This force is responsible for the beta decay of a neutron into a proton and for the nuclear reactions that fuel the Sun and other stars.”

These forces end up as the fundamental mechanisms of transportation because they both hold things together (form composites) so they move together and move things that are held

5 https://en.wikipedia.org/wiki/Geologic_time_scale

6 https://en.wikipedia.org/wiki/Template:Life_timeline

7 No opinion expressed about how this came to be. Perhaps for another book.

8 <https://www.britannica.com/science/subatomic-particle/Four-basic-forces>
<https://www.britannica.com/print/article/570533>

together by moving components (mostly electromagnetically and gravitationally). Of course as we drill deeper into the mysteries of subatomic stuff, things get messier, and at present, there is no definitive bottom to the analysis. So we will only go as far as it helps explain what this book is about.

Wind, as discussed earlier, is created by differences in pressure. So equalization of pressure differences carry air and other particles floating in air to other places. This is transportation by embedding in media that moves. Movement in this case is caused by higher level aspects of thermodynamics, and it applies to all sorts of other embedded movements. As sizes of composites increase, different forces apply in different ways to act as transportation systems.

One of the things we might do to better understand these issues is to create models that can be simulated for better understanding. A famous quote in this regard is “**All models are wrong, but some are useful**”⁹ Indeed models are not perfect version of reality, but some are useful for explaining by analogy or predicting for decision-making. In this book, I will use a model of living mechanisms in environments to show some of the concepts for better understanding. I do this by making them available for you to use and play with and perhaps some day for others to use as concepts for more extensive research. In this case, I have chosen Conway’s game of Life.¹⁰ This is not the board game of the same name, but rather a digital system simulating the conditions of an environment where cells reproduce or die off based on their environmental situation, and produce some interesting, perhaps astonishing results. We will refer to this herein as [Life] for simplicity.

The rules of the environment (I;.e., the physics of the space) are simple:

The universe of the Game of Life is an infinite, two-dimensional orthogonal grid of square cells, each of which is in one of two possible states, live or dead (or populated and unpopulated, respectively). Every cell interacts with its eight neighbors, which are the cells that are horizontally, vertically, or diagonally adjacent. At each step in time, the following transitions occur:

- Any live cell with fewer than two live neighbors dies, as if by under-population.
- Any live cell with two or three live neighbors lives on to the next generation.
- Any live cell with more than three live neighbors dies, as if by over-population.
- Any dead cell with exactly three live neighbors becomes a live cell, as if by reproduction.

One of the results from this simple environment is that it can implement a “Turing machine”¹¹, which means that such an environment can evolve any result that any other computer can compute (as is the case for computer viruses¹² and genetic biological systems that do genetic string search and replacement). Many other experiments have been performed showing different properties of even this simple system that are relevant to our discussion. One of the interesting issues this addresses is the potential that evolution is purely natural vs. the theory that God created life. What these sorts of models show is that, by analogy, random

9 https://en.wikipedia.org/wiki/All_models_are_wrong

10 https://en.wikipedia.org/wiki/Conway%27s_Game_of_Life

11 https://www.cs.virginia.edu/~robins/Turing_Paper_1936.pdf for a copy of “On Computable Numbers, with an application to the Entscheidungsproblem”, A. M. Turing, 1936.

12 F. Cohen, “Computer Viruses”, ASP Press, (1985) and dissertation at University of Southern California, 1986

generation of cells in simple environments can fairly rapidly lead to reproductive combinations of cell values (like combinations of matter leading to reproductive chemical or biological forms). This does not address the philosophical issues, but confirms the hypothesis of the world we live in being purely a result of random variation and selective survival.¹³

More complicated control systems

It seems inherent that transportation requires more complicated control systems than simpler things like maintaining a water level or a temperature. In order to transport something other than yourself, the self has to get the thing and the self into positions where the things can be attached or otherwise connected to the self. Then, while connected, the self has to move itself through the environment carrying the thing along from place to place. Then, at the destination, the self has to disconnect itself from the thing, leaving the thing at the destination place.

When we think about control systems in terms of states and transitions, the self has to go from an initial state not connected to the thing to a state connected to the thing, then maintain that state while moving from place to place, and change that state back to the unconnected state to release the thing. While in the connected state, movement almost certainly involves a complex coordinated act of multiple actuators, and for any general purpose transportation self that can go from multiple places to multiple other places, some sort of decision-making method must be in the control system along with the actuators required to act differently depending on the selection.

In most such systems in the natural world, the self gets to the thing, grabs the thing, moves it about to position it for carrying, moves itself about while holding the thing, then releases the thing in a controlled manner and moves itself away. If the thing grabs on to the self, the system is even more complicated, requiring coordination between the thing and the self. And many such systems have the self carrying more than one thing at a time, which makes it even more complicated for loading and unloading.

In the artificial world, people have designed various transportation systems like railroads, horse and buggy, and so forth. The wheelbarrow is an example of a transportation technology created by people. So is a slide. But these simple mechanisms, some without any internal control at all, have to be controlled by people or other far more complex control systems in order to operate effectively as transportation systems. We may float a bundle of logs down a river to get the logs from one place to another, but first we have to get the logs to the river, bundle them together, set them on their way avoiding getting stuck in the various natural hazards, stop them from going too far at the destination, get them back out of the water, and place them somewhere useful.

There are other factors to consider, like lifting and carrying capacity, how long it takes to get from place to place, energy required, hazard avoidance, and so forth. While designed systems can be designed to meet specifications, natural systems are what they are. We can and have bred horses to carry more weight over longer distances, but even then, they are not able to carry as much as elephants. Elephants can move pretty quickly (up to about 25mph) when they are motivated,¹⁴ and they can carry a lot,¹⁵ but not much more than they weigh (up

¹³ Note that in science, confirmation is not proof of a theory, while refutation would be disproof.

¹⁴ https://tpwd.texas.gov/publications/nonpwdpubs/young_naturalist/animals/animal_speeds/

¹⁵ <https://tsavotrust.org/how-strong-is-an-elephant/>

to about 6 tons). Other than cliffs, they can pretty much push anything in their way aside. But they do tend to go around larger obstacles. Ants on the other hand can carry far more than their weight, but no ant today can carry anything like a pound. And they certainly do not run at a sustained 25 mph or even 1 mph. The different factors in their control systems are oriented toward their physicality. How fast what parts have to move, how they are coordinated, how they connect to things, and so forth.

The molecular and cellular levels

In a control system, we can move chemicals about, for example to change concentrations, by moving the substrates (water, air, other moving media) containing those chemicals. This applies at the chemical and cellular level where electromagnetic forces are the main force mechanism for most local movement. That's because the components at that scale are so light weight that gravitational forces have little effect on their relative movement in the cell or fluid. A fluid itself may move cells around at high speed, such as in a blood stream, but within the cell walls, movement is not subject to such currents at a level that overwhelms the connection of shaped molecules bonding. Fluid flows move atoms and molecules around until they encounter cells or other structures they bind to, and then local control systems take over.

Once external molecules get absorbed through the cell wall, then broken apart and reassembled, and eventually either become waste thrown back out, or part of the newly divided cell. Except of course those once external molecules that themselves, or as part of another living creature, act to destroy the cell, eating its parts to grow and reproduce, and thus we have the war of the microscopic organisms. It is ongoing and part of the fundamental underlying competition of life. But there are two other sorts of interaction that also happen where symbiosis is the order of the day^{16 17 18 19}:

- Organisms that 'go along for the ride' can end up merely staying stuck to the outside or internal parts of a cell, perhaps gaining energy or spare parts from the cellular mechanisms, and eventually parting ways, for example as the cell divides.
- Organisms that collaborate are in synergistic relationships where each organism benefits from the other, but they live together instead of competing for resources and killing each other off.

In most cases cells and related structures are composites that include small transportation systems as components, some moving internal components, and others moving the cell as a whole through the media in which it lives.

Recent results in transfer of mitochondria provide an excellent example of manufacturing and transportation between cells in organisms.²⁰ In this particular study, starting with prior results ("Intercellular mitochondrial transfer, the spontaneous exchange of mitochondria between cells, is a recently described phenomenon crucial for cellular repair, regeneration, and disease management.") the researchers turned some cells into biofactories ("stimulate

16 <https://www.genome.gov/genetics-glossary/Mitochondria>

17 <https://online-learning-college.com/knowledge-hub/gcses/gcse-biology-help/movement-of-substances-into-and-out-of-cells/>

18 <https://fiveable.me/ap-bio/unit-2/cell-compartmentalization/study-guide/HRfoDYQgTXrvyzeUlwu>

19 <https://opengeology.org/historicalgeology/case-studies/endosymbiosis/>

20 <https://www.pnas.org/doi/epdf/10.1073/pnas.2505237122>

mitochondrial biogenesis in cells to make them mitochondrial biofactories.”) producing excess mitochondria that is then transferred to recipient cells. The excess is emitted from the manufacturing cells and transfers to older cells resulting in more vigor in the older cells improving regeneration and restoration of cell function. While it may ultimately result in therapies that reverse aging, for our purposes, this demonstrates intercellular transportation, cellular manufacturing, and the path humans are taking to turn these biofactories and transportation capabilities of cells into artificial means to improve peoples' lives.

Manufacturing in the informational world is easily demonstrated by the many examples from [Life]. A simple structure of 5 cells called a “Glider” moves over time across the grid over time showing travel (technically it's also viral reproduction because it makes a copy of itself elsewhere in the environment of [Life]), while a “Glider Gun” is a more complicated structure that manufactures Glider after Glider without end, shooting one after another in an endless stream across the environment. A “Puffer Glider” manufactures glider gun after glider gun, each manufacturing glider after glider.

The term “manufacture” here might be replaced with “produces”, the argument goes that to manufacture, you need to take in material to produce different material, and these examples don't do that. They just generate patterns from other patterns, and patterns are not material. A similar argument has been used to claim that these reproductive mechanisms are not life forms because they are informational. But this argument in its various forms fails when various definitions of life are carefully considered.²¹

Computer viruses were described very early on as being able to carry a payload.²² In essence, the reproductive mechanism can carry an arbitrary payload and a triggering mechanism that releases the payload under programmed conditions. Computer viruses act as transportation systems for informational payloads and manufacture copies of themselves as well as their payloads in compatible computing environments. They can carry any amount of code or data with them, but from a practical standpoint, the more code they carry the longer they take, the more space they use, and the easier they are to detect. However, a common method today is to have a virus carry enough code to reach out and transport additional code from elsewhere, thus the viruses used the Internet as a transportation infrastructure for code.

Computer viruses have also been shown to operate across multiple computing environments of dissimilar types by a trick in which the first few bytes act differently in different operating environments. For example, in a PC, the first byte might cause a jump into another portion of the virus code while in a mainframe the same byte might produce a non-jump operation. This can usually be generalized to many different environments. Today, there are a few common environments and they are readily differentiated without undue effort. Recent biological results show at least one example of a mechanism that causes different DNA replication depending on environmental conditions.²³

Larger life forms

Larger life forms move about and transport things in different ways. Mechanisms that move cells are transporting the rest of the cell in the media. Internally, components of cells transport

21 F. Cohen “It's Alive!!!” John Wiley and Sons (1994)

22 <https://all.net/books/virus/SCVirusBook.pdf> 1990

23 <https://scitechdaily.com/scientists-have-discovered-an-organism-that-breaks-biologys-golden-rule/>

other components within the cell. Multi-cellular organisms move by coordinated movement of cells and transport other things along with those movements. Multicellular organisms live past the lives of individual cells by self-repair mechanisms, and move both by movement of cells and by growing new cells in new locations. Trees grow new limbs and leaves and lose old ones, while internally they transport water and other nutrients from roots to branches and leaves, and energy gathered from leaves to other parts of the tree. Trees are also media for transporting other creatures, like monkeys and squirrels. Self-repair of multicellular organisms requires manufacturing, transportation, and infrastructure, all present in all such life forms.

Fungi

Fungi emerged about 1.5 Bya (billion years ago) and colonized land about 635Mya.²⁴ They lived in water and had flagella that made movement possible, and may have had a role in oxygenating Earth's atmosphere in the neoproterozoic oxygenation event between 540 and 850 Mya.²⁵ They became abundant perhaps 250Mya and may have been the dominant life form (they are about 100% of the fossil record) in that time frame. The earliest related features in the fossil records are from about 2.4Bya, around the time of the Great Oxygenation Event,²⁶ and fungi seem to have never had a mass extinction event. Most fungi can reproduce asexually or sexually²⁷

Fungi break down dead plant and animal matter and release essential nutrients for plant growth. An interesting example of a larger life form is fungi, in particular those that support life in forests and other soil environments.^{28 29} Fungi (references omitted from the quote):

“Due to their ability to produce a wide variety of extracellular enzymes, they are able to produce enzymes, break down all kinds of organic matter, decomposing soil components and thereby regulating the balance of carbon and nutrients . Fungi convert dead organic matter into biomass, carbon dioxide, and organic acids. Many species of fungi possess the ability to act as an effective biosorbent of toxic metals such as cadmium, copper, mercury, lead, and zinc, by accumulating them in their fruiting bodies. Though these elements may inhibit their growth and affect their reproduction. The diversity and activity of fungi is regulated by various biotic (plants and other organisms) and abiotic (soil pH, moisture, salinity, structure, and temperature) factors. Fungi can be found in almost every environment and can live in wide range of pH and temperature.”

In terms of transportation, they absorb (break down into components, separate components, and transport bad things into their own structures), transform (take in, process, and push out), engineer soil structure (move soil components around and restructure them), and they move themselves via passive dispersal of spores by wind and water and active movement of mycelium through soil and decaying wood.³⁰

24 https://en.wikipedia.org/wiki/Evolution_of_fungi

25 https://en.wikipedia.org/wiki/Neoproterozoic_oxygenation_event

26 https://en.wikipedia.org/wiki/Great_Oxidation_Event

27 https://en.wikipedia.org/wiki/Sexual_selection_in_fungi

28 <https://www.frontiersin.org/journals/microbiology/articles/10.3389/fmicb.2018.00707/full>

29 <https://pmc.ncbi.nlm.nih.gov/articles/PMC5932366/pdf/fmicb-09-00707.pdf>

30 <https://www.snexplores.org/article/secret-forest-fungi-partner-with-plants-and-help-the-climate>

Fungi 'trade' with plants distributing carbon and carrying messages³¹. They are not animals or plants, and they appear to have some form of memory, but no obvious central nervous system. They move phosphorous from area to area³², they 'hoard' nutrients when they are plentiful³³, and they form networks between plants to recycle soil nutrients and water and regulate plant community dynamics. In this sense, they act as control systems for plants in micro-ecosystems.

An interesting example of transportation for communication is that common mycelial networks (CMNs) can transfer allelo-chemicals and pathogenic fungal disease resistance signals between plants. Transport of these sorts operate at meters or more per day, but are directed, as opposed to wind.

Fungi also do some very interesting things like grow in high radiation areas, such as damaged nuclear facilities, in some cases absorbing radiation and turning it into energy in a similar manner to how plants absorb light and turn it into energy.³⁴ Thus some fungi appear to have nuclear (radiation) powered transportation systems.

Animals

Wind carries spores, water carries eggs, ice flows carry mammals, and nature provides all manner of other media for transportation as well as transportation of self as the media moves. But animals are, for the most part, in a different class. Animals are creatures that consume organic matter and are able to move. Of course we see that certain plants and fungi do this in more limited ways. But in terms of transportation, moving from place to place under self-locomotion brings the ability to transport other things, and at rates far exceeding those of other living organisms. It also involves control systems that operate in real time and deal with complex external events, for example, fast enough to counter gravitational time frames for falling objects and for their own movement to leap from place to place.

Internal organs of animals manufacture cellular structures and transport these composites as components throughout their bodies using built structures as infrastructures for that transport. They perform repair tasks that break down broken components, carry them away for reuse or extrusion, and replace them with newly manufactured components.

Ants and bugs (insects)

Ants may withstand pressure up to 5,000 times their body weight³⁵. That's like a 100 lb person surviving 500,000 lbs (250 tons) of pressure. When I was in grade school, I came home one day and bragged that I was the 2nd strongest kid in my class.

My parents asked me:

"How do you know?"

31 <https://pmc.ncbi.nlm.nih.gov/articles/PMC3917958/>

32 <https://www.sciencedirect.com/science/article/pii/S0960982219304907>

33 <https://nph.onlinelibrary.wiley.com/doi/10.1111/nph.17055>

34 <https://www.bbc.com/future/article/20251125-the-mysterious-black-fungus-from-chernobyl-that-appears-to-eat-radiation>

35 <https://entomologytoday.org/2014/02/11/ants-can-lift-up-to-5000-times-their-own-body-weight-new-study-suggests/>

and I answered:

“How do you think I know?”

I will not describe the measurement process used for getting these results on ants.

Pest control companies claim ants can carry 50 times their body weight, but these advertisements are not scientific results. Science indicates that the larger the ant, the less it can carry relative to its body weight. Ants on average carry only about 8.78 times body mass, carry remains an open question in the scientific community.³⁶ Dragging is different than carrying of course, and many ants drag instead of carrying loads. In terms of speed, they tend to follow an equation like $P=f*v$ where P is Power, f force, and v velocity. Ants have a total maximum power consumption rate, and go faster with lesser loads. They go slower up hill than level or downhill, and have challenges with rain and wind. They have different gaits for different loads under different conditions, and maximum walking speeds vary substantially with species, with the fastest ants going up to 108 body lengths per second with their legs undertaking about 50 strides per second.³⁷ Ants can travel up to a mile a day, but no measurements we found show what weight they can carry at what speed over what distance. There are about 22,000 species of ants, and only about 13,000 of them have been classified.³⁸

Many other crawling creatures (insects - I tend to call them bugs) carry things to and from places as part of nesting behaviors, food transportation and storage, and manufacturing safe living quarters. All of the ones I have looked into carry things with them from place to place and are thus transportation mechanisms. But ants are particularly interesting because of their operation as convoys. Ants that find something, while transporting, leave a pheromone trail that other ants follow.³⁹ These processes can be quite complex using communications through chemicals to lay and adapt paths away from danger, toward food and nest, and so forth.^{40 41 42}

Internal transportation within insects is quite different from that of other animals.

- **Ants** and most insects have an internal structure that performs a function similar to a heart in that it moves fluids around the body to transport energy, oxygen, and other material from place to place.⁴³ This includes movement between internal organs, actuators, sensors, and control mechanisms. They don't have lungs, but they do take in oxygen to support chemical processes through a distributed system of tubes. Some ants also farm (manufacture in our sense) and transport fungi forming a sort of coevolution between the particular subspecies.⁴⁴

36 https://cob.silverchair-cdn.com/cob/content_public/journal/jeb/222/12/10.1242_jeb.199240/5/jeb199240.pdf

37 <https://www.nationalgeographic.com/animals/article/silver-saharan-ants-fastest-desert>

38 <https://en.wikipedia.org/wiki/Ant>

39 <https://medium.com/the-new-outdoors/how-ants-find-their-way-81a8d1d77f28>

40 <https://www.ant-shack.com/blogs/ant-articles/ant-superhighways-exploring-trail-formation-and-navigation-tactics>

41 <https://pmc.ncbi.nlm.nih.gov/articles/PMC5142812/>

42 <https://pmc.ncbi.nlm.nih.gov/articles/PMC3291321/>

43 <https://antkeepers.com/pages/anatomy-of-ants>

44 <https://scitechdaily.com/scientists-discover-ant-associated-fungus-is-far-more-than-a-villain/>

- **Cockroaches**^{45 46 47} have spread around the world by hitchhiking largely on human transportation systems. They have brains of a sort, but most of their internal operations don't require the brains in order to work. The control systems for other parts of their bodies tend to do just fine even when the brain is destroyed. They breathe through holes in their bodies, and after living about a week without their heads, they die of thirst because the head is required to drink. They move at about 50 body lengths per second (a human would have to run at 200 mph to do the equivalent). Like ants, they have tube-like hearts that pump fluids to internal organs, and thus they have an internal transportation system. They don't tend to carry anything with them, but rather eat and defecate as they walk about. They give birth to living young and care for them to a limited extent for a limited time. They have been around in early forms for about 320 Mya and have apparently evolved significantly over that time frame. They tend to live in close association with groups, like ants, follow or avoid trails others have taken based on pheromone trails, and appear to have group decision-making of a sort.
- **Termites** evolved from cockroaches and have similar characteristics in terms of transportation within their bodies. So do **centipedes**.
- **Beetles**⁴⁸ on the other hand have wings and fly around. They tend to have outer shell wings that open to allow inner wings to do the flying. There are more than 400,000 different types of beetles, comprising about 25% of all animal species on Earth. They have a number of internal transportation systems and have been around for almost 300 million years.^{49 50} Some interesting internal transportation mechanisms include:
 - **Respiration:** Oxygen enters through holes (spiracles) in the abdomen and travels directly to tissues via tracheal tubes, limiting maximum size but allowing efficient gas exchange. This is similar to other insects. Some beetles inhale air and hold it in an internal bubble as they travel underwater. They even operate sorts of gills that replenish the oxygen in the stored bubble as they swim.
 - **Digestion:** Highly compartmentalized guts house symbiotic microbes that produce enzymes to digest cellulose and lignin, crucial for wood-boring beetles. They consume food in the head and transport it to the gut to break it down and convert it to useful components, the components being then transported through the body via the circulation system.
 - **Circulation:** A dorsal heart pumps hemolymph, a fluid containing oxygen and nutrients, through the body, similar to other insects.⁵¹
 - **Thermoregulation:** Some species actively regulate body temperature, using metabolic rates and behaviors like thermoregulation to survive varied climates.

45 <https://en.wikipedia.org/wiki/Cockroach>

46 <https://pubmed.ncbi.nlm.nih.gov/25564743/>

47 <https://animals.howstuffworks.com/insects/cockroach.htm>

48 <https://www.wildlifetrusts.org/wildlife/how-identify/identify-beetles>

49 <https://en.wikipedia.org/wiki/Beetle>

50 <https://pmc.ncbi.nlm.nih.gov/articles/PMC6447812/pdf/fphys-10-00319.pdf>

51 https://en.wikipedia.org/wiki/Circulatory_system#Open_circulatory_system

Use of insects and other similar creatures for transportation of disease have been undertaken by people in the context of biological warfare.^{52 53 54} Called “warfare”, insects have been used to transport disease such as cholera or plague or as a direct attack mechanisms, for example, against crops. Under the Biological and Toxic Weapons Convention of 1972⁵⁵, use of insects to administer agents or toxins for hostile purposes is deemed to be against international law. Non-state actors may use bio-terrorism in the form of entomological vectors. Historically, the Black Death was carried by fleas, and there are claims this may have been through an intentional release, but proof of many such historical claims is dubious. In World War 2, France, Germany, Japan, Canada, the US, and probably other countries pursued biological warfare programs. The same is true of the Cold War, at least up till the 1972 agreement. Modern accusations include things like accusing the Chinese of launching COVID-19 as a biological weapon. But regardless of such accusations, insects are clearly disease vectors.

Transportation of disease through insects seems to be one of the most common paths for global spread. Of course other animals also carry diseases, but because of their small size, enormous numbers, and presence in all environments where other animals (and most plants) live, insects are one of the most pervasive transportation systems for microscopic organisms other than wind and water.

As we move up the complexity of biological organisms, we will see that at every level, disease is transported and communicated (as in communicable diseases) by and between living creatures, and these transportation mechanisms are foundational to all living creatures.

Bees, bats, birds, and other flying creatures

Flying creatures tend to transport smaller loads compared to body mass, but they go far faster and further than crawling creatures. For the most part, these fliers carry food and nesting material from place to place.

Some creature that move through the air only carry themselves, and in some cases don't so much fly as float. *Trichonephila clavata* spiders travel in a similar manner to plant seeds, by floating on the wind, except the spiders do this by spinning a parachute-like web and controlling their flight, like a person might control a hang-glider. They are making their way across the US today as an invasive species. Their ability to fly (or glide or whatever you might call it) makes it essentially impossible to stop them from spreading without doing great damage to the environment because they live throughout forested areas and spread within and between such areas.⁵⁶ This species can reach 6-8 inches long, has bright yellow and blue markings, but flight speed is limited largely by their gliding skill and wind velocity.

While some birds do not fly, flying birds can get quite large. In prehistoric times, some birds were massive. The record holder seems to be the Quetzalcoatlus⁵⁷ with a 10-11 meter

52 <https://entomologytoday.org/2018/07/13/sting-defeat-brief-history-insects-entomological-warfare/>

53 https://en.wikipedia.org/wiki/Entomological_warfare

54 <https://pmc.ncbi.nlm.nih.gov/articles/PMC12569269/>

55 https://en.wikipedia.org/wiki/Biological_Weapons_Convention

56 https://www.earth.com/news/giant-joro-spider-species-is-methodically-spreading-across-the-us/#google_vignette

57 <https://en.wikipedia.org/wiki/Quetzalcoatlus>

wingspan, about 5 times the height of a human being. Many of the largest birds do not and apparently never did fly.⁵⁸

Flying birds transporting things are typically far smaller, usually less than 50 lb in weight, less than 5 ft in length, and typically birds of prey. They tend to hunt small ground creatures or fish, circling above them, waiting for the moment to dive and snatch them. They either swallow them (usually fish) or take them away for meal preparation and consumption. They pick up worms and take them to the nest for feeding, sometimes partially digesting them first. And birds attack other bird species for food, territory, and whatever other reasons they may have. Some tend to live in groups (flocks) and collaborate for safety (alarming and communicating about things like the weather) and hunting (flocks tend to gather where others are hunting to join the hunt). But others are more isolated, hunting alone, and forming only small groups.

Birds often have to take prey back to a nest or other location in order to process it because the hunter becomes the hunted with food already in hand. Of course they manufacture their nests by transporting nesting material from other locations and assembling it, usually on a tree branch, but in some historical cases, within other structures, including caves.

I have seen a hawk take a crow and have the flock of crows harass the hawk as it held and tried to leave with the crow it had caught. But other than feathering a nest or carrying food back to chicks or for safe processing, I am unaware of any case of birds transporting for other purposes. Generally birds fly with loads no larger than themselves, and travel at normal flight speeds when carrying these loads. Maximum speeds for most birds is in the 60-100 mph range, but for actual distance you have to add wind speed.⁵⁹ In a storm, that can be well over 100 mph, which means, if flying into the wind, birds travel backwards relative to the Earth. Birds also transport bird flu, and the list goes on.

Bees are one of the most widely studied species on Earth, perhaps because they produce honey that people eat, pollinate plants used for food, and have been used by humans for these purposes for about 8,000 years.⁶⁰ They have been around for more than 100 million years and the social bees (about 9% of all species of bees) collect material to build nests, tend to the young, and have a caste system. They create and maintain a hive, clean cells in the hive, circulate air with their wings, collect water, forage, guard the hive entrance, and co-evolve with plant species which they use for food and pollinate as they go from plant to plant. Their anatomy includes a myriad of complex mechanisms that transport fluids throughout their bodies.^{61 62 63} Thus they transport both internally (with glands, stomachs generating nutrients that circulate, a digestive track, etc.), at the nest level (air and supplies), for external supplies (foraging), and between other life forms (pollination).

Carrier pigeons have been used for perhaps 5,000 to 10,000 years by people.⁶⁴ They transport small amounts of physical goods, usually pieces of paper, but not always, over long

58 https://en.wikipedia.org/wiki/List_of_largest_birds

59 https://tpwd.texas.gov/publications/nonpwdpubs/young_naturalist/animals/animal_speeds/

60 <https://bestbees.com/bee-facts/>

61 <https://askabiologist.asu.edu/honey-bee-anatomy>

62 <https://www.idmybee.com/bee-anatomy.html>

63 <https://americanbeejournal.com/the-internal-anatomy-of-the-honey-bee/>

64 <https://armyhistory.org/tools-of-war-messenger-pigeons/>

distances, ranging up over 1,000 miles.⁶⁵ They have been used for messaging at least since 1350 BC⁶⁶ and among the applications are news reporting, postal services, smuggling, intelligence, and wartime operations. They can deliver terabytes of data faster than Internet for distances in the 50 mile range and possibly much further. Birds were used in nation-state military communication applications up to the early 2000s, but this has apparently ceased.

As long distance rapid transport, flying creatures are also carriers for diseases, including:⁶⁷

- **Mosquitoes:** Dengue, Zika, West Nile Virus, Chikungunya, Yellow Fever, Equine Encephalitis and parasites like Malaria, and Dog Heartworm (Dirofilaria).
- **Flys:** bacteria causing diarrhea, cholera, dysentery, tuberculosis, anthrax, sleeping sickness, Tularemia, Leishmaniasis and Sandfly Fever.
- **Ticks:** Lyme Disease, Rickettsial diseases, tick-borne Encephalitis, and Tularemia.
- **Fleas:** plague (fleas transport it from rodents to humans).
- **Birds:** Psittacosis, Influenza, Newcastle disease, Yersiniosis, Mite,, Salmonellosis, Arbovirus, Histoplasmosis, and Cryptococcosis.⁶⁸
- **Bats:** Ebola, Nipah, Rabies, measles, mumps, canine distemper, and hepatitis C.⁶⁹

Most of the identified diseases are human in nature, but of course diseases effecting crops and other creatures are also transported by flying creatures. One of the challenges to overall understanding is that humans are focused largely on themselves, their crops, and their pets when it comes to disease detection and prevention. Ecological concerns have increased focus on other species, and of course forests are attended to in substantial degrees. But every living creature (as well as computer life forms) is susceptible to transported disease.

Fish, marine mammals, and fluidic beings

The marine environment brings its own very different environment from land, underground, air, and outer space. Temperature gradients, light levels, pressure levels, fluid dynamics, currents, waves, underwater plumes from suboceanic magma, solar heating, lunar gravitational pull, and who knows what else, all effect the environment of water creatures:

- **Temperatures:** Water temperatures range no lower than freezing (before it turns to ice) and no higher than boiling (where it becomes a gas called steam). Most water creatures cannot survive being frozen or boiled for very long. Different creatures seek different temperatures.
- **Light:** The deeper you go under water, the less light filters through from the Sun, and creatures that live in the deep tend to have deprecated or no light-based (i.e., vision) sensors. The distance you can see, even with bright lights, deep under water is quite limited, among other things because water is full of other things than H₂O.
- **Pressure:** The deeper you go, the higher the pressure. For creatures with internal bladders or other things that hold air or other compressible fluids or gasses, the

65 https://en.wikipedia.org/wiki/Homing_pigeon

66 <https://www.ooma.com/blog/communications-history-homing-pigeons/>

67 <https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases>

68 <https://journals.asm.org/doi/epub/10.1128/microbiolspec.iol5-0004-2015>

69 <https://pmc.ncbi.nlm.nih.gov/articles/PMC7132474/>

pressure changes reverse proportionally with volume ($PV=nRt$ again) and inversely with temperature. As you go down, temperature usually gets lower, pressure higher, and volume reduces. As you go up, unless you release things under pressure, they expand, eventually potentially blowing up the structure holding them. Other processes also release dissolved gasses like nitrogen leading to things like the bends (a.k.a. compression sickness).⁷⁰

- **Currents:** These movements of water range from the flow of a stream or river to ocean currents that move massive bodies of water from place to place. Rip currents near shore are dangerous to people, who get swept away from shore as well as marine mammals whose babies sometimes get swept away from parents. Ocean currents are exemplified by “One of the largest currents on the globe is the West Wind Drift, or Antarctic Circumpolar current. It is about 2,500 km wide with a maximum speed of 0.4-0.5 m/sec, and has a volume measured in the Drake Passage of 230 million m³/sec. The Gulf Stream current has a volume on the order of 80 million m³/sec, and the Kuroshio current, 50-60 million m³/sec. The greatest speed of these currents [is] 2-3 m/sec.”⁷¹ So 6-9 ft per second and, at 264.172 gallons per cubic meter, 50M cubic meters is 13,208,602,618 (13.2 billion) gallons per second. That’s a lot of water. By comparison, the Los Angeles water district flows about 5,000 gallons per second, or 435M gallons per day, or roughly 12 billion gallons per month.^{72 73} Ocean currents carry warm and cold water around loops at different depths mixing different water and its content, bringing temperature differences to the air above, helping produce storms and other global effects, and changing over time.⁷⁴ Creatures living in the oceans tolerate only certain temperature ranges, and tend to move with the currents to climates where they find food and can undertake other activities.
- **Solar heating:** The sun heats the oceans, and that usually means that the surface is hotter than the depths with gradients all the way up and down. This changes based on time of day and to a lesser extent conditions in the atmosphere.
- **Magma heating:** Under the floor of the oceans, there are other layers.⁷⁵ In particular, the oceanic crust is on top of the upper mantle,⁷⁶ and underwater volcanoes⁷⁷ bring lava as they build the ocean floor. This is hot stuff, which boils the bottom of the ocean where it erupts or seeps in through fissures. The heat gets dissipated over distance within the ocean, producing a temperature gradient from superfluid (above 407 °C = 765 °F) to boiling under pressure (below 765 °F) to nearly ice cold (32 °F) and with gradients in salt levels associated with the temperature.
- **Fluid dynamics:** In the oceans, the fluid dynamics of water interacting with all of the other things it encounters causes activities ranging from fast flows through under-

70 https://en.wikipedia.org/wiki/Decompression_sickness

71 <https://www.oceansatlas.org/subtopic/en/c/572/>

72 <https://www.ladwp.com/who-we-are/water-system>

73 https://ladwp-jtti.s3.us-west-2.amazonaws.com/wp-content/uploads/sites/3/2021/10/04152431/2020-2021_Facts_and_Figures_Digital_final.pdf

74 https://en.wikipedia.org/wiki/Ocean_current

75 https://en.wikipedia.org/wiki/Internal_structure_of_Earth

76 https://en.wikipedia.org/wiki/Earth's_mantle

77 https://en.wikipedia.org/wiki/Submarine_volcano

ocean structures to whirlpools, and more generally lots of local high intensity mixing as moving water rubs up against and interacts with physical boundaries and plants.

- **Waves:** Wind on the surface of water bodies causes waves that can get into hundreds of feet in height (peak to valley), and waves are also formed by other effects like earthquakes that produce tsunamis, the ever-present small meteor strikes⁷⁸ that produce waves as well as other effects, and at a small scale, waves caused by whales and other creatures. Ocean surface waves travel at speeds up to about 35 mph, but, tsunamis can travel up to about 600mph, 79% of the speed of sound (mach 0.79).⁷⁹
- **Other stuff:** Natural water sources and repositories are full of the excrement of water creatures that live there as well as whatever runs off from shore, comes up from the bottom, scrapes off surfaces as water flows, or drops in from above.

From a standpoint of the evolution of life forms, higher temperatures correspond to more randomness which means more random stuff being produced but harder to survive because of all the changes taking place. As gradients go from higher to lower temperature, there are places where any level of randomness between the extremes can be found, so creatures that survive and reproduce at any level have a place they can life, grow, evolve, and over the span of the gradients, evolve and live at other places in the spectrum. There are also light, pressure, current, and other gradients mixed in with temperature and salinity, which forms a tremendous capacity for supporting a wide range of different life forms. Add to that the fact that all of the other stuff is present in different quantities and densities in different places in the gradients, and you have different foods for different life forms to metabolize.

The rate of change of the conditions under the surface of oceans is not as rapid in some ways as the space above and on land. Because it takes more energy to change momentum of water than air (higher density of water) there is less dramatic change like storms and wind under the ocean. As a result, these gradients tend to remain relatively stable over longer time frames, leading to more opportunity for multiple generations without substantial change as compared to changes within the lifetime of most over land and air creatures.

However, at times, the changes can be massive. For example, two major asteroid impacts happened just over 3Bya and caused the oceans to boil for a year.⁸⁰ And every 500 million years for a while we have gotten a hit that caused mass extinctions. But hopefully for now we are good to go until we find ways off of Earth.

Autotrophs⁸¹ presumably emerged in and from the sea long ago, and are at the bottom of the global life food chain / food web. Without them, according to modern science, no life would continue on Earth, at least in the form of life today. New life could emerge and evolve as a new bottom of a food chain/web emerged, but that would be generation from scratch. The way this works is:

“An autotroph is an organism that can convert abiotic sources of energy into energy stored in organic compounds, which can be used by other organisms. Autotrophs produce complex organic compounds (such as carbohydrates, fats, and proteins)

78 https://en.wikipedia.org/wiki/Impact_event

79 <https://scripps.ucsd.edu/news/voyager-how-fast-and-far-do-waves-travel>

80 <https://www.smithsonianmag.com/smart-news/asteroid-impacts-once-made-earths-oceans-boil-whole-year-180955332/>

81 <https://en.wikipedia.org/wiki/Autotroph>

using carbon from simple substances such as carbon dioxide, generally using energy from light or inorganic chemical reactions. Autotrophs do not need a living source of carbon or energy and are the producers in a food chain..."

Among the autotrophs are "algae, which live in water and whose larger forms are known as seaweed,... phytoplankton, tiny organisms that live in the ocean[, and] some types of bacteria."⁸² Most use photosynthesis converting sunlight, water, and CO₂ into glucose used to build, among other things, cell walls. Some autotrophs use a process called chemosynthesis to produce food using chemical reactions such as combining oxygen with methane or hydrogen sulfide instead of sunlight. They can also live and thrive in extreme environments.

In the infrastructure of the Earth over time, supplies of naturally occurring carbon dioxide and water or other similar chemical compounds along with energy sources are consumed by autotrophs to manufacture organic compounds that are transported by the fluid environment and consumed by the next higher level components of the food chain / web. Up the food web it goes to various microscopic organisms consumed by bigger organisms, consumed by bigger ones, and as the saying goes, "the big fish eat the little fish".

While many microscopic organisms have microscopic motors that move physical structures so as to 'swim', they are predominantly borne by water currents from place to place along with everything else around them. As creatures get bigger, they move further faster by use of body structures like fins moved by muscles and controlled by larger control systems than those within cells. Internal organs supply digested food compounds throughout the bodies.

Internally, most single cell organisms in water are similar to those on land. They have cell walls and internal mechanisms for reproduction through similar internal mechanisms. They operate in much richer food environments in water when operating alone, but within bodies of larger creatures, the bodies provide the environment for the cells and other components, controlling temperature (or not, depending on the species), providing transportation of organic materials, oxygen, and so forth through the body, and with some sort of control system acting on sensors communicated to the control mechanisms which generates actions, with all the same sorts of limitations of all control systems.

Fish respiration is through gills that exchange oxygen, carbon dioxide (CO₂), ammonia, acid, and water. The exchange happens as the movement of the fish through water pushes the water over the gills, and as such, a fish that stops swimming stops breathing.⁸³ Some marine creatures may breath through skin, digestive tracts, or other means, and some can live out of water for days, and some even breath by getting air from the surface like marine mammals do. Fish breath rhythmically and these rhythms are controlled by the brain stem. They breath faster under more physical movement, and their heart pumps blood through their closed circulatory system bringing oxygen in from the gills, providing it throughout the body, and bringing back out CO₂. Fish hearts have one pump, while there are two pumps in most amphibians and reptiles. They have a digestive system that transports food into the relevant organs that manufacture nutrients from food sources and delivers it to the blood stream, they have internal organs to filter the blood, and they have muscular systems for movement. In short, fish and other marine creatures have internal transportation, manufacturing, and infrastructures within their bodies just like other living creatures.

82 <https://education.nationalgeographic.org/resource/autotroph/>

83 https://en.wikipedia.org/wiki/Fish_physiology

There are many other sea creatures, each with different particulars, but the pattern is the same in terms of internal operations taking in food, transporting it internally, manufacturing nutrients from it and defecating waste product, and transporting nutrients and waste through internal infrastructure. On the other hand, few of them carry things around, other than carrying parasites that attach to their bodies and other relationships with living creatures that cooperate for mutual success.

One of the most stunning examples of cooperation for success is feeding frenzies where a combination of marine mammals, larger fish, and birds actively collaborate to consume a school of fish. This comes in different forms. One is called “carousel feeding”⁸⁴ which includes herding behaviors to bring a school of fish into a ball, move the ball toward the surface, and then feed on them. This is one example involving “bubble net feeding” where whales use air bubbles as a form of a net to catch and eat fish.⁸⁵ This happens when whales blow bubbles out of their blow holes to surround a school of fish, then swim through the net with their mouths open to eat in volume. The use of air bubbles as a tool is just one example of tool usage by marine mammals. I have personally watched multi-species feeding at “Bird Rock” along the shore of the Pacific ocean. Whales, dolphins, sea lions, and sea birds collaborate to collect, contain, and consume a ball of fish.⁸⁶

Sea otters use rocks as tools to open shells of clams, crabs, and snails.⁸⁷ Bottlenose dolphins also use tools⁸⁸ as do a number of other aquatic animals including some fish, cephalopods, crabs, urchins, and possibly others.⁸⁹ Marine mammals like sea otters actually lived on land before deciding to return to the sea, which may be related to their tool usage, but dolphins are native to the oceans. Tool use is taught to children by parents, and in most cases, tools are items found in the environment rather than altered or manufactured for specific use.

Tools have to be carried from place to place, and as a result, this is a case of transportation. The use of tools is a form of what we call manufacturing here, where raw material is transformed into usable material; in the case of sea otters, rocks for food extraction. Tools are used by marine creatures for concealment, decoration, protection, shelter, and burrowing. Catfish lay eggs on detached leaves and move the leaves when danger is present. Many water creatures use water jets or waves as tools. Octopodes use objects to prop open internal bivalves, allowing them to eat the soft prey. Sea otters also use objects as hammers, or use one as a hammer and another as an anvil, use rocks to pry prey from attachments on the sea bed, and sometimes wrap crabs in kelp to immobilize them while consuming other captured prey. Dolphins have been observed using mud plumes to catch prey. Bottlenose dolphins in Shark Bay, Australia tear basket sponges up from the seabed and wear them over their beaks for protection while foraging. All of these examples of tool use involve transportation of tools, and some demonstrate manufacturing. All involve sensors, actuators, communications, and control by a creature of an external device, as is essential to tool usage.

84 https://en.wikipedia.org/wiki/Carousel_feeding

85 <https://www.marinemammalcenter.org/news/your-visual-guide-to-whale-breaching-lunge-feeding-and-other-behaviors>

86 <https://www.montereybaywhalewatch.com/blog/humpback-whales-dolphins-sea-lions-and-sea-birds-in-multi-species-feeding-aggregations-in-monterey-bay/>

87 https://en.wikipedia.org/wiki/Tool_use_by_sea_otters

88 https://en.wikipedia.org/wiki/Bottlenose_dolphin

89 <https://pmc.ncbi.nlm.nih.gov/articles/PMC4027413/pdf/rstb20120424.pdf>

There are other aquatic examples of transportation of course, such as dolphins and other sea creatures carrying people to safety, fish carrying eggs in their mouths, and sea otters carrying pups on their stomachs.

Land animals (predominantly mammals)

Many of the same sorts of examples of transportation and manufacturing that apply to marine animals apply to land animals. Animals carrying things for their living quarters are common enough. Food storage, building dams, kangaroos and their pouches, animals carrying their young with their mouths, and so forth demonstrate many examples of transportation. And of course the bodies of land animals operate with infrastructures used to transport nutrients manufactured in bodily organs into and waste out of body parts. But the infrastructure on land is quite different from within bodies of water. On land, small distances underground (e.g., in tunnels and caves), and small distances above ground (e.g., in trees), climate and other conditions are infrastructure for living systems. They key issues include:^{90 91 92 93}

- **Temperatures:** Weather brings temperatures from about -40 (Celsius or Fahrenheit are the same at this temperature) to perhaps 140°F. Most larger life forms operate well for a period in the range from 0°F to 90°F, but typically, they live in different latitudes based on temperatures at those latitudes and proximity to the ocean and altitude. As altitude increases above sea level, temperature tends to go down, while near oceans, the temperature on shore is moderated by the oceans. More detailed climate maps are available, and the climate changes over time, but life typically fails when temperatures fall outside of these bounds for more than months to years.

Most plant life cannot survive above the “tree line”⁹⁴ because of low temperatures and humidity, which means that animals living there have problems finding adequate food. At lower pressure and temperature, there is less humidity in the air, and this creates problems for many life forms as well. The tree line follows the line where the seasonal mean temperature is approximately 6°C or 43°F. This is typically 300-1,000 m (~1,000-3,000 ft) below the permanent snow line, above which water is almost always frozen.

- **Light:** Light on the surface comes predominantly directly from the sun, and bounced off the moon at night, depending on the lunar cycle and your location. Near the poles, the sun shines nearly 24 hours at one time of year and essentially 0 hours a half solar cycle away, daylight hours varying between the extremes. Because heat and luminance for photosynthesis come predominantly from the Sun, this impacts temperature and the ability for plant life to survive and grow. Sunlight also effects weather, as discussed earlier.
- **Air and Pressure:** The atmosphere is a mix of about 78% nitrogen, 21% oxygen, 0.04% carbon dioxide, and 0.96% other gasses, mostly argon.⁹⁵ This mix has changed over geologic time frames, but is fairly stable today. It is denser closer to sea level than at higher altitudes, making the availability of oxygen at higher altitudes too limited for

90 <https://education.nationalgeographic.org/resource/earths-changing-climate/>

91 <https://sciencetrek.org/topics/climate>

92 <https://www.studentsofhistory.com/climate-zones-biomes>

93 <https://www.worldatlas.com/climate/the-climate-zones-of-the-world.html>

94 https://en.wikipedia.org/wiki/Tree_line

95 <https://scied.ucar.edu/learning-zone/air-quality/whats-in-the-air>

many life forms to remain for long. People have problems breathing over 12,000 ft, and really need oxygen to survive much above that.⁹⁶ Human habitation is considered viable at about 5,000m (~15,000 ft), and Mt. Everest is at 8900m (about 25,000 ft), where oxygen levels are about 30% of that at sea level. There are many side effects of altitude that go along with temperature and pressure.

- **Currents:** Above ground, air currents are the major issue for life forms. As discussed earlier, differential air pressure causes air currents. Terrain acts to amplify air currents (the same volume in a smaller space has increased velocity which is also how wings work). The higher you get the faster the wind goes because there is no terrain to slow or stop it. Wind gradients cause various phenomena as well, like wind shear and tornadoes, and other rotating wind storms.⁹⁷ Above the ⁹⁸planetary boundary layer (in the peplosphere), wind is uninterrupted by land. Wind speeds can go up to 250mph in the upper atmosphere. Interesting wind maps are widely available online for example from NASA data over decades⁹⁹ and real-time information from independent sources¹⁰⁰. The jet stream can flow air at up to 300mph but typically flow at less than half of that.¹⁰¹
- **Rain and water:** Rain is the delivery system for water to land on Earth.^{102 103 104 105} While there are also underground rivers and water near oceans, for the most part, rain is the way water evaporating from oceans gets delivered to land. It is transported through the air in clouds, moved by wind, and drops in different places depending on conditions. There are places with more and less rain, and these change over time, turning deserts into lush lands and lush lands with lakes into deserts in geological time frames due to plate tectonics (movements of the plates underlying major land masses),^{106 107 108} and possibly, human behavior.¹⁰⁹ More or less rain stems from the water cycle which includes evaporation, condensation, and precipitation.¹¹⁰ It is effected by a variety of factors, including rain shadow¹¹¹ which causes more rain on the side of a mountain that wind comes from (the windward side) than the side wind goes to (the leeward side), it rains more in cities than surrounding rural areas,^{112 113} and it rains more in areas closer to bodies of water, particularly oceans and places like the

96 <https://pmc.ncbi.nlm.nih.gov/articles/PMC1114067/pdf/1063.pdf>

97 https://en.wikipedia.org/wiki/Wind_gradient

98 https://en.wikipedia.org/wiki/Planetary_boundary_layer

99 <https://www.earthdata.nasa.gov/topics/atmosphere/wind-speed>

100 <https://zoom.earth/maps/wind-speed/>

101 https://en.wikipedia.org/wiki/Jet_stream

102 <https://www.nesdis.noaa.gov/about/k-12-education/atmosphere/what-makes-it-rain>

103 <https://science.howstuffworks.com/nature/climate-weather/atmospheric/weather6.htm>

104 <https://science.howstuffworks.com/nature/climate-weather/atmospheric/weather8.htm>

105 <https://science.howstuffworks.com/nature/climate-weather>

106 <https://pubs.usgs.gov/of/2004/1007/climates.html>

107 <https://eos.org/features/three-times-tectonics-changed-the-climate>

108 <https://scied.ucar.edu/learning-zone/how-climate-works/investigating-past-climates>

109 <https://www.smithsonianmag.com/science-nature/what-really-turned-sahara-desert-green-oasis-wasteland-180962668/>

110 <https://en.wikipedia.org/wiki/Rain>

111 https://en.wikipedia.org/wiki/Rain_shadow

112 <https://cockrell.utexas.edu/news/most-cities-receive-more-rainfall-than-surrounding-rural-areas-global-study-shows/>

113 <https://www.pnas.org/doi/10.1073/pnas.2311496121>

leeward side of the great lakes where there is lake effect snow.¹¹⁴ Rain forests have internal water systems including internal mechanisms wherein water gets trapped in the canopy and rains back down on the floor, humidity levels tend to be high, and enormous varieties of life forms compete for resources, adapt, co-evolve, and live out their lives.^{115 116 117} In deserts, few creatures can survive because of the lack of water and normally less moderated temperatures that are higher in the day and lower at night.^{118 119} Rain water turns into snow in low temperatures, and snow packs on high mountains leading to melting periods where streams, rivers, and lakes form, creating longer-term repositories for water around which local ecosystems grow and evolve. Rain and resulting water eats away at soil as the water brings it along, enriching soil in some places and eroding it in others.¹²⁰ It cuts canyons over the ages,^{121 122} and water tends to find a way into small crevices because of the small molecular size (H₂O) and freezes or flows to break apart most natural surfaces.

- **Volcanoes, earth movement, and other violent events:** Under the surface of the Earth, magma builds up pressure until it is released as lava through the surface. While underwater we don't see it as much, when we get volcanoes on land, they make for big hot bright displays, spew molten lava and ash thousands of miles through the atmosphere, and release nutrients that land on the land (as well as the water), and form rich soil for future growth.¹²³ They sometimes blow massive chunks of land from the volcano itself over miles when they erupt, and if you are in the way, you are likely no longer. Earth movement, including earthquakes¹²⁴, movement related to sink holes (a.k.a. shake holes)¹²⁵ and other subterranean movements or changes produce effects on living creatures on, slightly above, and slightly below ground. The shaking, movement of soil, depressions, and disruptions of structures and habitats at different scales produces different effects over the short term. Impact events¹²⁶, from things like comet strikes, cause earth movement, but also spew amounts of debris into the atmosphere. Depending on the magnitude of the event, strikes can shroud the whole planet in relative darkness for years and cause mass extinctions. Planetary effects like this are relatively infrequent, happening only every 50 million years or so, but the last one was about that long ago. So don't look up? Earth movements can also cause tsunamis on shore that can go miles inland, killing people and disrupting whatever is in their way.¹²⁷

114 https://en.wikipedia.org/wiki/Lake-effect_snow

115 https://en.wikipedia.org/wiki/Tropical_rainforest

116 <https://blog.fundtheplanet.net/amazon-rainforest/unveiling-the-mysteries-of-rainfall-in-the-rainforest-facts-and-figures/>

117 <https://news.columbia.edu/2010/10/07/7458/>

118 https://en.wikipedia.org/wiki/Desert_climate

119 <https://education.nationalgeographic.org/resource/desert/>

120 https://en.wikipedia.org/wiki/Soil_erosion

121 <https://science.nasa.gov/earth/earth-observatory/the-colorado-river-cuts-a-canyon-150622/>

122 <https://education.nationalgeographic.org/resource/canyon/>

123 <https://en.wikipedia.org/wiki/Volcano>

124 <https://en.wikipedia.org/wiki/Earthquake>

125 <https://en.wikipedia.org/wiki/Sinkhole>

126 https://en.wikipedia.org/wiki/Impact_event

127 <https://en.wikipedia.org/wiki/Tsunami>

- **Soil and plant life:** As infrastructure for animal life goes, other life is critical. Animals do not generate their own bio-supplies directly from physics or chemistry, but rather consume existing biomass from other living organisms. As such, they are higher in the food chain / web, but also dependent on the biological beings lower in the chain. Other than eating each other and insects, water creatures and plants are the food source for land animals.
- **Gravity:** For aquatic and microscopic life, gravity has little direct effect. That's because aquatic creatures float at whatever level they are in balance between gravity and density relative to water at depth. For microscopic creatures, gravity produces very little impulse even if they fall at terminal velocity.¹²⁸ In addition, microscopic creatures are so light, it is easily overcome by convection currents (resulting from hot air rising as colder air which is denser pushes it up), and they may stay suspended in the atmosphere for long periods. Larger creatures in water often use gases to change their depth as well as their ability to swim. But for land creatures, things happen faster, like acceleration of falling objects at $\sim 32\text{ft/s}^2$. Whether it is the creature falling or objects falling on them, the effects can be catastrophic for the individual. Gravity also holds the atmosphere, making it denser as it gets closer to the surface, and keeps everything from floating away. Gravitation effects from the moon effect large bodies of water substantially, but on the ground, the difference is negligible for most organisms. Land animals have to overcome the force of gravity in order to stand on limbs, and they need to stand on limbs to travel at higher than crawling speeds. Their size, weight, and need to move at speed effectively then limits viable bones, muscles, and other structures of the body.^{129 130 131} For example, blood has to go up hill in the body to reach the vertical expanse of the creature by overcoming gravity, and this means the heart must have enough pumping power and the blood infrastructure has to be able to handle the pressure of the pump. Gravity seems to favor creatures that take food in at or above the level where they excrete waste, presumably because gravity has a role in the digestive manufacturing process.
- **Other stuff:** I have probably missed some other major infrastructure elements that form the environment in which land animals live. But whatever I have missed, I am confident you will come up with.

This is the environment in which life emerged started perhaps 3.7Bya, and large sea creatures evolved starting something like 800Mya¹³², but vertebrates apparently emerged from the sea and have lived and evolved on land for only about 300 million years.¹³³

Amphibians

Amphibians emerged from the sea in the Devonian period, around 370Mya.¹³⁴ They have 4-limbs. And evolved in semi-aquatic habitats. In their development process, they undergo a metamorphosis from an aquatic life form to an air breathing adult with lungs. They apparently

128 https://en.wikipedia.org/wiki/Terminal_velocity

129 https://www.naturalhistorymag.com/editors_pick/1974_01_pick.html

130 <https://www.dinox.org/sizelimit.html>

131 <https://physics.stackexchange.com/questions/72641/why-is-there-a-size-limitation-on-animals>

132 <https://naturalhistory.si.edu/education/teaching-resources/life-science/early-life-earth-animal-origins>

133 https://en.wikipedia.org/wiki/Vertebrate_land_invasion

134 <https://en.wikipedia.org/wiki/Amphibian>

started out as fish with articulated fins that evolved into limbs and developed primitive lungs that allowed them to live on land. They dominated for a time because there was no real competition for land animals but were displaced by early reptiles. Today there are something like 8,000 species of amphibians, predominantly frogs, ranging in size from 0.3 inches to a salamander species that grows up to almost 6 ft. But historically they got as large as 20ft during the Jurassic period.

They are cold blooded and thus lack a control system for internal temperature, so their metabolism is slow compared to warm-blooded creatures. Their skin has glands that, among other things, secrete poisonous venom. They have 3-chambered hearts and breath by a pump action that draws in air through nostrils, close the nostrils and push the air into their lungs via throat contractions. They have a single bladder that expels nitrogenous waste as urea. They have a central brain, a spinal cord, and nerves throughout their bodies. Their brain is 'relatively simple' and contain motor areas for actuation and sensory areas for sensing. Brain areas associated with regulating sleep in humans "is thought to produce the hormones involved in hibernation and aestivation in amphibians". They have a liver, gall bladder, and pancreas; store and use fat for energy usage over time; have a kidney that filters blood, and some can breathe through their skin. Some have unisexual reproduction, most lay eggs and use environmental concealment to protect eggs during reproduction, but some grow eggs internally but exit after metamorphosis. The parents do not feed their eggs internally like we see in mammals. "It is estimated that in up to 20% of amphibian species, one or both adults play some role in the care of the young."

Most hunt by sight and eat anything that looks right, even flannel. Movement triggers feeding, but olfactory senses lead them to areas where prey may appear. Those that live in caves feed by smell, may chew lightly to subdue prey, but swallow and digest without first grinding it up.

They have not been found to transport any loads other than themselves and, other than internal manufacturing and infrastructure, they do not display any apparent external tool use or other building behaviors. They make sounds and some may use this to communicate, but their communication has not yet been well decoded by humans. Sound is apparently used as part of mating rituals, but no larger scale coordination using sound have been identified to date. There are many different variations and they have a wide range of capabilities developed over the ages. They eat smaller creatures of all sorts, ranging from bacteria to small mammals, and are eaten by snakes, birds, and other amphibians. Their population is in decline, and this decline endangers some species higher up the food chain/web.

Reptiles

Reptiles emerged in the late Carboniferous period about 320Mya.¹³⁵ They "are defined as animals that have scales or scutes, lay land-based hard-shelled eggs, and possess ectothermic metabolisms." but definitions vary, and the early evolutionary history remains a bit unclear. They generally emerged from tetrapods which are also the ancestors of amphibians. There are 4 different orders of reptilia:

- **Testudines** (turtles) date back to around 220Mya. They are mostly herbivorous, with some feeding exclusively on small marine organisms. They have a shell that defends against predators but slows movement on land.

135 https://en.wikipedia.org/wiki/Evolution_of_reptiles

- **Sphenodontia** (almost extinct today) are represented by only 2 endangered species in New Zealand today.
- **Squamata** (mostly snakes and lizards) have a movable quadrate bone (giving them upper-jaw movement), and have horny scales and hemipenes. Snakes¹³⁶ have a high metabolism compared to others in the group and can move very quickly to strike prey at tremendous speed. They found that all snakes could accelerate at more than 160 meters per second squared and reach speeds up to 3.5 meters per second,¹³⁷ covering 13.6-16.7 centimeters in 66-74 milliseconds.¹³⁸ Compare this to reflex speeds for mammals that respond in between 60 and 400 milliseconds and you can see that the race goes to the snake. They can travel up to about 18 miles per hour (sidewinder),¹³⁹ and snake venom can kill a human within 30 minutes of the strike. 18 miles per hour corresponds to a 100 yard dash in about 11.36 seconds, but you better accelerate real fast to beat the strike speed. Human reflexes are about 150ms for touch, 170ms for sound, and 200ms for sight so no chance against a fast deadly snake once you get too close.¹⁴⁰
- Crocodilia (crocodiles)¹⁴¹ appeared about 83.5Mya, but their ancestors come from about 250Mya and diversified after that.

Mammals

Mammals emerged from reptiles about 300Mya.¹⁴²

*“A basic cladogram of the origin of mammals. Important developments in the transition from reptile to mammal were the evolution of warm-bloodedness, of molar occlusion, of the three-ossicle middle ear, of hair, and of mammary glands.”*¹⁴³

Dinosaurs emerged perhaps 230Mya¹⁴⁴ and continued till about 66Mya when, other than avian dinosaurs, it is thought they were all killed off by a meteor strike, and only small land animals survived those events. With this mass extinction of dinosaurs, mammals came to be the dominant land species in Earth.

Transportation: Carrying capacity for animals ranges broadly, but the comfort range is in about 20% of body weight.¹⁴⁵ Camels carry up to ½ their body weight and elephants carry 25%, war dogs can carry 30%, and of course there are other variations. Pulling power runs on the order of 3 times body weight, for example, horses, dogs, and other domesticated animals can pull this much on a wheeled cart, which they only have when humans come into the picture. We don't know the capacities of animals no longer alive, but this is probably a good guide to the maximums for transportation over time. **Sprint speed** for animals runs up

136 <https://en.wikipedia.org/wiki/Snake>

137 <https://www.sciencenews.org/article/venomous-snakes-strike-fast-vipers>

138 <https://www.nature.com/articles/531416a>

139 <https://a-z-animals.com/animals/snake/snake-facts/fastest-snakes/>

140 <https://bionumbers.hms.harvard.edu/bionumber.aspx?s=n&v=4&id=110800>

141 <https://en.wikipedia.org/wiki/Crocodylia>

142 <https://en.wikipedia.org/wiki/Mammal>

143 https://en.wikipedia.org/wiki/Evolution_of_reptiles

144 <https://www.amnh.org/dinosaurs/dinosaur-facts>

145 <https://www.enworld.org/threads/carrying-capacity-of-animals-and-creatures.684137/>

to about 70 mph over short distances.¹⁴⁶ Of course this is with no load. Under load, they slow considerably, but for the most part, they only carry things like food from where they get it to where they eat it and only sprint to get or escape becoming food.

Infrastructure built by animals has generally been limited to nesting areas where they build various sorts of shelters, and paths they travel over, under, around, and through between water, food, shelter, and other locations in their daily lives. They dig, hunt, gather, and otherwise operate to survive and thrive in areas suitable to them, ranging over distances associated with their food sources and patrol areas. Some interact often or always with others of their own species, operating in organized packs and family groups at one extreme, while most cats are largely loners operating in their own territories and only gathering for reproductive activities.

Manufacturing in some of the more 'advanced' (for lack of a better word) animals create dams and other similar structures out of available material, pack them with mud for relative permanence, and live in or near them, catching food, and controlling their local environments. They learn from each other generation to generation, and develop social hierarchies and similar structures, largely consisting of local groups and with little or no long range communication between groups.

Other animals: If you are offended by the fact that I am largely ignoring land non-mammals and other creatures, I apologize. But for limited clarity, to the best of my understanding, things are pretty much the same with various variations for other creatures. They all have transportation, manufacturing, and infrastructure in a hierarchical internal structure and are all limited in external aspects of these items in similar ways.

Physiologically, mammals differ from other vertebrates by having milk-producing mammary glands for feeding their young, a broad neocortex region of the brain, fur or hair, and three middle ear bones.¹⁴⁷ Their bodies tend to have 4 limbs, most using all 4 for moving on land, but some have limbs adapted for sea, air, tree, trees, or underground life. Bipedals are adapted to move with the two lower limbs, using the other two for hands. Mammals range in size from just over an inch to almost 100 ft (blue whale). Lifespan varies from two years for the shrew to 211 years for the bowhead whale. Except for monotremes which lay eggs, they give birth to live young and most offspring get nutrition from the mother during gestation through a placenta.

Primates

Primates¹⁴⁸ emerged about 100Mya.¹⁴⁹ They have large brains relative to body size and an increased reliance on vision and smell. They are more developed in monkeys and apes, and less so in lorises and lemurs. Some primates, including gorillas, humans and baboons, are primarily ground-dwelling rather than arboreal, but all species have adaptations for climbing trees. They are among the most social of animals, forming pairs and family groups. Non-human primates have at least four types of social systems, defined by the amount of movement by adolescent females between groups. They have slower development rates, reach maturity later, and have longer lifespans, and display a lot more social learning and

¹⁴⁶ https://en.wikipedia.org/wiki/Fastest_animals

¹⁴⁷ <https://en.wikipedia.org/wiki/Mammal>

¹⁴⁸ <https://en.wikipedia.org/wiki/Primate>

¹⁴⁹ https://en.wikipedia.org/wiki/Timeline_of_human_evolution

parental dependency for survival. They are considered (by humans) to be the most cognitively advanced animals and have been recorded using tools. They may communicate using facial and hand gestures, smells and vocalizations.

Primates have skulls containing the brain and various sensory organs with forward facing eyes on the front of the skull, binocular vision for distance perception, a bony ridge above the eye sockets that reinforces weaker bones in the face put under strain during chewing. Primates developed color vision most other mammals do not have. Strepsirrhines have a postorbital bar, a bone around the eye socket, to protect their eyes, and 'higher primates' have fully enclosed eye sockets. They have evolved toward shorter snouts and have a range of dental patterns. They usually have 5 digits on each limb, a keratin fingernail on the end of each finger and toe, and sensitive pads on the bottom of hands and feet with increased sensitivity and numbers of sensors on the fingertips. Most have opposable thumbs that allow some to use tools. The combination of opposing thumbs, short fingernails and long, inward-closing fingers has allowed some species to develop brachiation (swinging by the arms from tree limb to tree limb) as a significant means of locomotion. Primates move by brachiation, bipedalism, leaping, arboreal and terrestrial quadrupedalism, climbing, knuckle-walking or a combination of these.

Primates have complex social systems where females or males transfer between groups, and groups collaborate for protection, hunting, child rearing, and other functions. There is shared responsibility for parental care and territorial defense, offspring leave the parents' territory during adolescence, and many other patterns are found in different groups. In some cases, large groups up to 600 animals collaborate for periods before returning to their smaller groups. Cooperative behaviors include social grooming (removing skin parasites and cleaning wounds), food sharing, and collective defense against predators or of territory. Aggressive behaviors are associated with competition for food, sleeping sites, mates, and establishing dominance hierarchies. They use vocal communication including at least alarms, singing, and mating, and combine them with facial expressions and recognition. They use hand and arm gestures, covert communications to avoid predators, prey, and competitors, and can communicate over long distances vocally. Some have consonant- and vowel-like sounds that maintain meaning over great distances, and have for something like 2.4Mya.

Primates have what people consider to be advanced cognitive abilities,¹⁵⁰ but then people as primates consider themselves to be the most advanced, and as such, this viewpoint is biased.

- Some primates make and use **tools** to get, farm, or otherwise manufacture **food** and to show social **displays**.
- Some can **collaborate** for doing tasks, team up for **influence**, and use groups to produce and demonstrate **rank** in social hierarchies.
- Many are status conscious, **manipulative**, and use **deception**.
- They can **recognize** kin and **bond** to parents and family groups.
- They can **learn** to use **symbols** and understand aspects of human language including some **relational syntax** and concepts of **number and numerical sequence**.

150 https://en.wikipedia.org/wiki/Primate_cognition

Research in primate cognition explores problem solving, memory, social interaction, a theory of mind, and numerical, spatial, and abstract concepts. Newer species tend to have higher measured scores in these areas, but there is a lot of variation within and between groups.

Tool use and manufacturing by non-hominids is substantial.¹⁵¹

- **Chimpanzees**, for example, pick up leafy twigs, strip them of leaves, and use them to dip (a.k.a., fish) for ants and termites; make forms of sponges out of leaves and moss to absorb water.
- Crab-eating **macaques** use stones to open nuts, oysters, other bivalves, and sea snails
- There are some reports of **bonobo** using tools in the wild and they use them in captivity.
- **Orangutans** in Borneo scoop catfish out of small ponds and have learned to jab sticks at catfish to scare them out of the ponds into their hands. Sumatran orangutans break off tree branches, snap off the twigs, fray one end, and dig in tree holes for termites.
- An adult female western lowland **gorilla** was observed using a branch to test water depth to help cross a pool of water, another used a detached shrub trunk during food gathering, and another used a log as a bridge.
- **Mandrills** use tools for self-grooming. They sometimes clean their ears with modified tools, one stripped down a twig making it narrower, and it to scrape dirt from under its toenails.
- Chacma **baboons** use stones as weapons dropped over a cliff of the canyon they sleep and retreat to when threatened.
- A non-ape example is a **capuchin** that beat a snake to death with a dead branch. Individuals were observed cracking nuts using a stone to hold them and another to crack them.
- **Lemurs** in controlled environments have been trained to use tools,

It seems the more we look for tool manufacturing and use in primates, the more we find it.

Are there others?

It's worth noting that there are underground creatures we may not know about, creatures that may live in extreme environments ranging from the middle of stars to outer space, and on and on. We don't know what we don't know.

¹⁵¹ https://en.wikipedia.org/wiki/Tool_use_by_non-humans

Domestication

Domesticated animals and plants have long been used by many species.^{152 153 154 155 156} Some of the examples include leaf-cutter ants that gather leaves to cultivate a fungus that grows on the leaves, about 330 species of termite colonies build mounds that provide temperature controls and other environmental conditions for growing fungi, damselfish grow algae for food, ambrosia beetles cultivate fungus for food, several ant species herd and milk aphids that produce honeydew, marsh periwinkles farm fungus on leaves as food, spotted jellies grow algae inside their tissues for food, yeti crabs farm bacteria for food, melissotarsus ants raise herds of scale ants and eat the meat, the slime mold dictyostelium discoideum forms networks through soil, wood, and leaf litter, and hunt and feed on bacteria from those networks, and gophers farm roots feeding them with their feces and eating them for about half their diet. Note the manufacturing processes involved, and the infrastructures they build for this farming.

The co-evolution of biological control systems

Over history, the control systems of various creatures also evolved and became more complex, ultimately leading to what we call brains.¹⁵⁷ This has been discussed briefly along the way, but it's time for a drill-down and summary.

The concept of a central nervous system (a.k.a., brain) conceals the underlying hierarchical control system of most multi-cellular organisms. As we have seen, many creatures have many levels of control, including sub-cellular, inter-cellular, reflexes, organs with their own control systems (sometimes called brains) that interact with other organs in feedback loops, and various components and composites of centralized overall control.

The fundamental theory of evolution asserts that we get random variation and selective survival. Variation comes from inherent instabilities in the underlying mechanisms such as imperfect DNA transcription, and external forces ranging from radiation breaking apart physical mechanisms to introduction of external material into and through reproductive processes like sexual reproduction mixing genomes of various phenomes and diseases and other mechanisms that add to or alter DNA. Selective survival merely means that some of the resulting phenomes live long enough to reproduce. Thus the genotype reproduces and produces the phenotype which reproduced by generating the next genotype.

The changes in the environment over time, including both the non-living and living sources of climate, food, shelter, predation, and competition for resources kill off some phenomes and let others grow and multiply. While large variations in temperature, available oxygen, and other similar things favor phenomes that move or reproduce from place to place and phenoms without complex internal processes for moment to moment survival, speed, stealth, strength, and rapid high-level control mechanisms favor those who are in instantaneous battle for momentary survival. Fungi are still here and thriving, even in nuclear reactors, while many other creatures have come and gone.

152 <https://www.treehugger.com/animals-that-know-how-to-farm-4869292>

153 <https://itotd.com/articles/451/non-human-farmers-classic/>

154 <https://www.newscientist.com/article/dn20630-zoologist-the-first-non-human-meat-farmers/>

155 <https://news.ufl.edu/2022/07/gophers-first-known-mammal-farmer/>

156 <https://roundglasssustain.com/wild-vault/microscopic-agriculturists>

157 https://en.wikipedia.org/wiki/Evolution_of_the_brain

Simple and distributed nervous systems

The evolution of brains start with **nervous systems**.^{158 159} Nerves are specialized cells called neurons that use electrical signaling in their internal multi-cellular control systems. They are an adaptation of mechanisms of action potentials that previously used chemical signaling to sense and act. As animals started consuming larger food particles and moving around more, they developed muscles for actuators and neurons for signaling results of sensations. They also developed internal organs and internal fluid transportation systems. The fluids get filled with nutrients via digestion and also get other compounds from internal organs. Other internal organs clean the blood and produce waste excreted from the body. All of these involve control systems, some local to the organs, and most connected to other control systems in a distributed or hierarchical fashion.

Simple nerve networks directly connecting sensors to actuators eventually produced more centralized longer-strand nerves that still exist in sponges and other life forms. In some colonies of creatures, nerve-like networks pass between independent colony members forming a larger sort of joint nervous system used in digestion for sponges.

Jellyfish and related animals have **distributed neural networks** but no central nervous system. The networks consist of; sensors that sense chemical, tactile, and visual signals; motor neurons to contract the body wall; and control neurons that detect sensory activity patterns and signal groups of motor neurons. In some cases control neurons are clustered into larger control systems.

Most current animals are **bilateral** in that they have left and right sides that largely mirror each other externally. They are thought to have descended from a common worm-like ancestor that appeared in the Cryogenian period, 700–650 Mya.

“The fundamental bilaterian body form is a tube with a hollow gut cavity running from mouth to anus, and a nerve cord with an especially large ganglion at the front, called the ‘brain’.”

In early development of embryos, one of two paths lead to creatures with mid-body brains and brains in heads. Some worms have different nervous systems for male and female forms, but a complete study of other life forms has not been completed to date.

Spinal chords and fused ganglia with limited organs

Arthropods, like as insects and crustaceans, have a series of **ganglia**¹⁶⁰ connected by a nerve cord comprising two parallel structures running along the length of the belly. Some ganglia are fused, forming a “**brain**”. The head section has a “brain” that includes protocerebrum which processes vision, from the compound eyes¹⁶¹ deutocerebrum which processes olfactory and pheromonal information from the antanae, and tritocerebrum which

158 https://en.wikipedia.org/wiki/Evolution_of_nervous_systems

159 <https://onlinelibrary.wiley.com/doi/10.1002/bies.201700024>

160 Per various dictionaries online, “a structure containing a number of nerve cell bodies, typically linked by synapses, and often forming a swelling on a nerve fiber” and “a mass of nerve tissue containing cell bodies of neurons external to the brain or spinal cord”.

161 https://en.wikipedia.org/wiki/Composition_of_the_protocerebrum

integrates sensory inputs from the subesophageal ganglion. The subesophageal ganglion,¹⁶² which is just behind the rest of the brain, has three pairs of fused ganglia that control the mouth, salivary glands, and some muscles.

Note that in these creatures, the neural networks control glands that produce chemicals and those chemicals alter the environment in some body parts. Glands directly connected to other tissue, such as salivary glands produce chemical compounds used in food digestion. The control system doesn't have direct feedback from these productions, while there is direct feedback from muscle contraction which triggers nerve impulses.

Vertebrate brains and bodies

Vertibrates¹⁶³ developed brains and bodies that are far more complicated than many earlier forms. There are multiple complex interconnected systems that have local and remote control mechanisms with local and systemic effects.¹⁶⁴

Body systems include^{165 166 167} respiratory, circulatory, nervous, endocrine, reproductive, lymphatic, muscular, immune, skeletal, urinary, and integumentary systems. In this coverage, the drill-down is to the level of the control systems involved, without details of the chemical, electrical, or other processes underlying them. An attempt is made to provide some sense of the extent to which complex interacting (networked) and hierarchical control systems are involved in the complex organisms of life and how they involve transportation, manufacturing, and infrastructures within and between the various systems. Throughout this section, technical terms are used freely, but in order to understand, you don't need to drill down into their definitions. You can if you want to, but just assume the names are names of different components of the composites used to distinguish them from other components.

Respiratory system

The Respiratory System:¹⁶⁸ Lungs of land-vertebrates get oxygen (O₂) from air and excrete carbon dioxide (CO₂). The oxygen is put into the blood stream and CO₂ extracted from it. The respiratory tract is divided into upper and lower, the upper including the nose, nasal cavities, sinuses, pharynx, and the larynx above the vocal folds while the lower includes the lower part of the larynx, the trachea, bronchi, bronchioles and the alveoli.

- Muscles controlled by the medulla oblongata in the brain stem control the lungs, mouth, and throat to support respiration. The respiratory surface is internalized as linings of the lungs. Gas exchange in the lungs occurs in millions of small air sacs called alveoli (in birds atria) that have a high volume blood supply that brings the air into close contact with the blood. A system of airways (hollow tubes including the trachea which branches into left and right bronchi), allow air sacs to interface with external air, where the bronchia enter the lungs and branch into progressively narrower secondary and tertiary bronchi which branch into many smaller tubes (bronchioles). Air

162 https://en.wikipedia.org/wiki/Supraesophageal_ganglion

163 <https://en.wikipedia.org/wiki/Vertebrate>

164 https://en.wikipedia.org/wiki/List_of_systems_of_the_human_body

165 <https://questhollow.com/high-school-biology-online-textbook/19-1-overview-of-vertebrates/>

166 <https://www.sciencedirect.com/science/article/pii/S0079610716300542>

167 <https://www.thoughtco.com/animal-organ-systems-4101795>

168 https://en.wikipedia.org/wiki/Respiratory_system

is pumped from the environment into the alveoli or atria by breathing which uses the muscles of respiration.

- The lungs expand and contract during the breathing cycle, drawing air in and out of the lungs. Contraction of the diaphragm contributes the most to the expansion of the chest cavity, while the intercostal muscles pull the ribs upwards causing the rib cage to expand during inhalation. The relaxation of all these muscles during exhalation causes the rib cage and abdomen to elastically return to their resting positions.
 - In forceful breathing (inhalation and exhalation), a more forceful and extensive contraction of the diaphragm is combined with intercostal muscles aided by accessory muscles to exaggerate the movement of the ribs upwards, causing a greater expansion of the rib cage. During exhalation the abdominal muscles actively contract to pull the lower edges of the rib cage downwards decreasing the volume of the rib cage, while pushing the diaphragm upwards deep into the thorax. The contracting diaphragm pushes the abdominal organs downwards. But the pelvic floor prevents movement, the belly bulges the front and sides. Mammals only use abdominal muscles during forceful exhalation and never during inhalation.
- The lung interiors are open to the outside air and elastically expand to fill the increased space. The inflow of air comes from the respiratory airways from the nose (the mouth is a backup). Automatic rhythmical breathing, is interrupted by coughing, sneezing, the expression of emotions (laughing, sighing, crying out in pain, exasperation sounds), and voluntary acts like speech, singing, whistling, and playing wind instruments, which use the same muscles. The Valsalva maneuver is a forceful exhalatory effort with a closed glottis so no air can escape, forcing abdominal contents to be evacuated through the pelvic floor. It can be carried out voluntarily but is usually a reflex caused by emptying the abdomen during difficult defecation or during childbirth.
- The mechanism of blood oxygenation is equalizing partial pressures of the respiratory gases in the alveolar with those in the pulmonary capillary blood with diffusion across the very thin blood–air barrier of alveoli walls. These walls are folded into about 300 million alveoli providing a $\sim 145 \text{ m}^2$ surface for gas exchange. The blood leaving the alveolar capillaries is distributed through the body by the circulatory system.
- The arterial partial pressures of oxygen and carbon dioxide are controlled in that a rise in arterial partial pressure of CO_2 or fall in O_2 will reflexly cause deeper and faster breathing until levels return to normal. The converse happens when the CO_2 partial pressure falls or O_2 rises so the rate and depth of breathing reduces until levels return to normal. The microscopic alveoli diameters can also be changed by the sympathetic and parasympathetic nervous systems to control available volumes for exchange. Changes are controlled by monitoring arterial blood gases (which accurately reflect composition of alveolar air) by the aortic and carotid bodies and by blood gas and pH sensors on the outside of the medulla oblongata in the brain. These sensors effect motor nerves activating respiratory muscles so that low oxygen brings faster and deeper breathing and high oxygen brings slower and less deep breathing. There are also oxygen and carbon dioxide sensors in the lungs that primarily determine diameters of the bronchioles and pulmonary capillaries, and are responsible for directing flow of air and blood to within the lungs. If these controls fail, a respiratory

acidosis (acid) or alkalosis (alkaloid) will occur. In the long run these are compensated by adjustments to concentrations in the plasma, but this takes time, so hyperventilation syndrome can occur when agitation or anxiety cause an animal to breath quickly and deeply, causing alkalosis in exhaling too much CO₂. Exercise increases breathing rates because extra CO₂ is produced by higher metabolism of exercising muscles. O₂ sensors in the smaller bronchi and bronchioles reflexively cause the pulmonary arterioles to constrict, the exact opposite of the corresponding reflex in the tissues, where low arterial O₂ partial pressure causes dilation. The kidneys also measure O₂ content in arterial blood (not partial pressure), and when O₂ content is chronically low, (e.g., at high altitude), oxygen-sensitive kidney cells secrete erythropoietin (EPO) into the blood that stimulates red bone marrow to increase red cell production, leading to increased red cells in blood and an increase in it's oxygen carrying capacity.

- Irritation of nerve endings within the airways (or nasal passages), can induce a cough reflex (or sneezing) that force air expulsion from the trachea (or nose). Irritants caught in mucus lining the respiratory tract are expelled externally or to the mouth. These reflexes are actuated by sensors in the respiratory tract (usually via the vegus nerve) to the medulla oblongata which actuates muscles producing contractions.
- A variety of molecules aid in lung defense, including secreted immunoglobulins (IgA), collectins, defensins and other peptides and proteases, reactive oxygen species, and reactive nitrogen species. These secretions act as antimicrobials to keep the airway free of infection. A variety of chemokines and cytokines are also secreted that recruit traditional immune cells and others to the site of infections. Lung vessels also contain a fibrinolytic system that dissolves clots and releases substances that enter and remove substances from within blood. The lungs also activate a hormone that is converted to angiotensin-II in pulmonary circulation that causes constriction and a resulting rise in blood pressure.
- The movement of gas through the larynx, pharynx, and mouth allow speech. Vocalization, or singing, in birds occurs via the syrinx, an organ located at the base of the trachea. The vibration of air flowing across the larynx (vocal cords), in humans, and the syrinx, in birds, results in sound. Because of this, gas movement is vital for communication purposes.
- Panting in dogs, cats, birds and some other animals provides a means of reducing body temperature, by evaporating saliva in the mouth (instead of evaporating sweat on the skin).

The complex myriad of redundant feedback mechanisms in control systems manufacture a variety of chemical and cellular components and uses the infrastructure of blood, electrical, and fluid transport to move components throughout the composite to assure that metabolism continues to function at properly controlled levels over varying external circumstances.

Circulatory system

The Circulatory System:¹⁶⁹ Supplies oxygen and other matter to cells via networks of arteries, veins, and capillaries that carry oxygen-containing blood cells to every cell in their bodies. The circulatory system is powered by the heart, a muscle that beats millions of times

¹⁶⁹ https://en.wikipedia.org/wiki/Circulatory_system

throughout a creature's lifetime, and is controlled by the medulla oblongata in the brain stem to carry the blood through the blood vessels to and from each cell in the body. In vertebrates it is a closed system in that blood never leaves the network of blood vessels. The circulatory system is complementary to the lymphatic system detailed elsewhere herein.

- The circulatory system has two divisions, a systemic circuit, and a pulmonary circuit. The pulmonary circuit is the network of blood vessels comprising the great vessels of the heart including large elastic arteries, and large veins, that brings blood to and from the lungs. The systemic circuit has other arteries, smaller arterioles, capillaries that join with venules (small veins), and other veins. Specific circulatory routes include circulation to the heart itself, cerebral circulation to the brain, renal circulation to the kidneys, and bronchial circulation to the bronchi in the lungs.
- Blood is a fluid consisting of plasma, red blood cells, white blood cells, and platelets. It carries oxygen and nutrients to tissues and collects and disposes of waste materials. Nutrients include proteins and minerals, and other components include hemoglobin, hormones, and gases such as oxygen and carbon dioxide. These substances provide nourishment, help the immune system fight diseases, and help maintain homeostasis by stabilizing temperature and natural pH.
- The heart pumps blood to all parts of the body. In humans, as an example,
 - **Oxygenation:** Blood from the superior and inferior vena cava enters the right atrium, flows through the tricuspid (right atrioventricular valve) into the right ventricle, is pumped through the pulmonary semilunar valve into the pulmonary artery to the lungs. Gas exchange occurs in the lungs, CO₂ is released, O₂ is absorbed, and the pulmonary vein returns oxygenated blood to the left atrium. In a separate circuit from the systemic circulation, the bronchial circulation supplies blood to the tissue of the larger airways of the lung.
 - The **systemic circulation** circuit loop delivers oxygenated blood from the left heart to the rest of the body through the aorta, the blood diffuses into the body via arteries which narrow into capillaries which exchange O₂ and CO₂ with cells, bring nutrients and other components to those cells, and removes other waste products pushed from the capillaries merged into venules which merge into veins and return the blood to the heart via the inferior and superior vena cavae, then via the right atrium to the pulmonary circulation for oxygenation.
 - Portal veins in humans collect products from capillaries in the **digestive tract** and, rather than leading directly back to the heart, go to a second capillary system in the liver.
 - The **brain** has a dual blood supply from arteries at its front and back. The supply is to the front of the brain and the posterior to the back of the brain and brain stem. The circulation from the front and the back join (anastomise) at the circle of Willis. The neurovascular unit, composed of cells and vasculature channels within the brain, regulates the flow of blood to activated neurons to satisfy their high energy demands.
 - The **renal** circulation supplies the kidneys and contains specialized blood vessels.

The circulatory system has multiple controls actuated locally and via the brain stem and driven by sensors in different organs, largely by adapting the size of the flow systems and the rates of activity. It is one of two major internal transportation systems (the other being the lymphatic system) that form the infrastructure for fuel to and waste from most of the body.

Nervous system

The Nervous System:¹⁷⁰ Enables animals to send, receive, and process nerve and sensory impulses, and move their muscles. Three main components are the central nervous system (which includes the brain and spinal cord), the peripheral nervous system (the smaller nerves that branch off from the spinal cord and carry nerve signals to distant muscles and glands), and the autonomic nervous system (which controls involuntary activity such as the heartbeat and digestion). The nervous system, as a control system, has faster loop times from sensors to actuators compared to mechanical- and chemical-based control systems because electrical signals travel faster over longer distances than other mechanisms. But these systems all interface to chemical and mechanical systems in order to sense and actuate, so the nervous system is also a mechanism for interfacing with compatible components and communication and control of those components for sensation and actuation.

- The nervous system detects environmental changes that impact the body, then works in tandem with the endocrine system to respond to such events. Nervous tissue first arose in worm-like organisms about 550 to 600 million years ago. In vertebrates, it consists of two main parts, the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS consists of the brain and spinal cord, and the PNS consists mainly of nerves enclosed bundles of the long fibers, or axons that connect the CNS to every other part of the body. Nerves that transmit signals from the brain are called motor nerves (efferent) and nerves that transmit information from the body to the CNS are called sensory nerves (afferent). Nerves are special cells (called neurons) comprised of cell bodies and fibers called axons that carry signals between nerves and other nerves, sensors, or muscles.
- Most axon bundles are in the PNS, even when the cell bodies of their neurons are in the brain or spinal cord. The PNS is divided as follows:
 - The **somatic** part are nerves innervating skin, joints, and muscles. The cell bodies are in the dorsal root ganglia of the spinal cord.
 - **The Autonomic** system contains neurons innervating internal organs, blood vessels, and glands, and are divided into sympathetic, parasympathetic and enteric systems.
 - The **sympathetic** is activated in emergencies to mobilize energy.
 - The **parasympathetic** is activated in a relaxed state.
 - The **enteric** controls the gastrointestinal system.
- At a cellular level, neurons send signals as electrochemical impulses through axons that connect to other cells through electrical synapses or release chemicals called neurotransmitters at chemical synapses. Receiving cells may be excited, inhibited, or

¹⁷⁰ https://en.wikipedia.org/wiki/Nervous_system

modulated. The nervous system also contains specialized glial cells that provide structural and metabolic support, nutrition, maintain homeostasis, form myelin to insulate neurons from each other, destroy pathogens and remove dead neurons, provide guidance cues directing axons of neurons to their targets, and participate in signal transmission. The spinal canal contains the spinal cord protected by vertebrae, while the cranial cavity containing the brain is enclosed and protected by a three layers of membranes (the meninges) with a tough leathery outer layer (the dura) and a skull.

- Perception abilities like vision, complex social interaction, integrated processing of concurrent signals that support language, abstract concepts, transmission of culture, and other cognitive and social abilities are supported by the brain, but the details of how all of this works are not yet well understood. Technologies like functional magnetic resonance imaging (fMRI) and electroencephalograph (EEG) provide imaging allowing the use of different areas of the brain to be observed during operation are being applied to learn more about this, but to date, the details are not known.^{171 172}
- A subset of synapses can form memory by long-lasting activity-dependent changes in synaptic strength. Long-term potentiation (LTP) operates at synapses using the neurotransmitter glutamate acting on the NMDA receptor that has an "associative" property so that if the two cells involved are both activated at about the same time a channel opens to permit calcium to flow into the target cell, which initiates a second messenger cascade that ultimately leads increased glutamate receptors in the target cell and increasing the effective strength of the synapse that can last for weeks or longer. The reward system that reinforces desired behavior depends on a variant form of LTP conditioned on an extra input from a reward-signaling pathway using dopamine as neurotransmitter. These forms of synaptic modification taken collectively lead to neural plasticity, a capability to adapt itself to variations in the environment.
- Sending signals includes a capability for neurons to exchange signals with each other, and networks formed by interconnected groups of neurons provide a wide variety of functions including feature detection, pattern generation, and timing. In 1943 it was shown that much simpler artificial neural networks are capable of universal computation.¹⁷³ Neurons can produce regular sequences of action potentials or bursts even in complete isolation. When intrinsically active neurons are connected to each other in complex circuits, the possibilities for generating intricate temporal patterns become far more extensive.
 - The simplest neural circuit is a reflex arc that begins with a sensory input, passes through a few neurons connected in series, and produces motor output. For example, the "withdrawal reflex" causes a hand to jerk back after touching a hot stove. Heat in sensory receptors in skin change electrical fields across the membrane exceeding an action threshold and transmitting along the axon to the spinal cord exciting synaptic contacts with other cells, some sending output to the same region of the spinal cord (others to the brain) activating motor neurons controlling arm muscles that, if the excitation is strong enough, generate action

171 <https://imotions.com/blog/learning/research-fundamentals/eeg-vs-mri-vs-fmri-differences/>

172 <https://pmc.ncbi.nlm.nih.gov/articles/PMC3073717/pdf/nihms256605.pdf>

173 McCulloch WS, Pitts W (1943). "A logical calculus of the ideas immanent in nervous activity". *Bull. Math. Biophys.* 5 (4): 115–133

potentials causing muscle cells to excite inducing muscle contractions causing arm joint angles to change to pull the arm away. There are also other nearby neurons that participate in the circuit and modulate the response, and signals from the brain can enhance or inhibit the reflex.

- More complex responses rely on signal processing in the brain. For example, movement of an object in the visual periphery causes sensory response in the retina that produces a motor response through the oculomotor nuclei of the brain stem, but the intermediate processing of signals pass through about 12 stages of integration involving the thalamus, cerebral cortex, basal ganglia, superior colliculus, cerebellum, and several brain stem nuclei. These signal-processing functions include feature detection, perceptual analysis, memory recall, decision-making, and motor planning.
 - **Feature detection** extracts information from combinations of sensory signals. In the visual system sensory receptors in the retina are individually capable of detecting intensity of light in the outside world, like pixels in a digital camera, but second-level visual neurons get input from groups of receptors, higher-level neurons get input from groups of second-level neurons, and so forth, in a hierarchy that extracts the information from the signal ensemble creating a neural representation of objects and their properties.
 - When **intrinsically rhythmic** neurons are connected by excitatory or inhibitory synapses, resulting networks can display a wide variety of dynamical behaviors including attractor dynamics, periodicity, and even chaos. A neural network using internal structure to generate temporally structured output without requiring a corresponding temporally structured stimulus, is called a central **pattern generator**. Internal pattern generation operates on time scales from milliseconds to hours or longer, for example, the circadian rhythm has a period of about 24 hours. All animals studied show circadian fluctuations in neural activity controlling circadian behaviors like the sleep-wake cycle. Experimental studies dating from the 1990s have shown that circadian rhythms are generated by a "genetic clock" consisting of a special set of genes whose expression level rises and falls over the course of the day. The circadian clock is influenced by light but operates even when no external cues are available. In mammals, all of the "tissue clocks" are synchronized by signals from a master timekeeper in the suprachiasmatic nucleus of the brain.
 - A **mirror neuron** fires both when an animal acts and when it observes the same action performed by another, "mirroring" the behavior of the other as though the observer itself acted. These neurons have been directly observed in primate species. Birds have imitative resonance behaviors and neurological evidence suggests the presence of some form of mirroring system. Human brain activity consistent with mirror neurons has been found in the premotor cortex, the supplementary motor area, the primary somatosensory cortex and the inferior parietal cortex. The function of the mirror system is a subject of much speculation.

Vertebrate **brains** contain complex neural structures, essentially, larger and more complex ganglia clusters with different connectivity, sizes, and components interacting with (sensing and acting on) different sensor and actuator composites, many of which themselves are

formed from the same sorts of components.¹⁷⁴ Brains scale disproportionately to other body parts and consume more energy per volume than other body parts in most cases.¹⁷⁵ Small mammals tend to have larger proportional brains compared to large mammals (e.g., whales). Using a regression analysis, different species have larger brains per body size than others, for example, lemurs fall well below the regression line while humans fall far above it. The brain stem and limbic system are largely based on ganglia, essentially tightly packed clusters of connected neurons with some axons connecting them to other locations. The cerebrum and cerebellum are based on a cortical architecture where neurons are arranged in layers a few millimeters thick.

All vertebrates have a **forebrain**, **midbrain**, and **hindbrain**.^{176 177 178} The peripheral nervous system is composed of all the nerves (i.e., neurons) not part of the brain, while the central nervous system is composed of all the nerves in the brain. Bundles of neurons in the periphery are called ganglia while in the CNS are called nuclei. In development, the forebrain gets divided into the cerebrum and the thalamus and hypothalamus, the midbrain is not further segmented, and the hindbrain separates into the pons, cerebellum, and medulla oblongata.

Brain stem

The **brain stem**^{179 180} is a small (about 2.6% of the total brain weight in humans) structure that connects the cerebrum to the spinal cord and cerebellum. It is composed, from the rest of the brain to the spinal cord (we will call it down), of three components; the midbrain, pons, and medulla oblongata. It is a bundle of control system components that control many of the basic vital functions of the organism. It is common to all mammals. This includes breathing, consciousness, blood pressure, heart rate, and sleep, among others:

- The **medulla oblongata** is the structure connecting the spinal chord to the pons. It contains the control mechanisms for the heart, breathing, blood pressure, and vomiting, so that even without the rest of a brain, these functions continue. Those who have dissected small mammals in science class may note that often the heart beats for a time after the animal is killed. Similarly, many 'brain dead' patients continue to have respiration, heart beat, and and maintain blood pressure for a time.
- The **pons** sits between the medulla oblongata and the midbrain, and contains many component 'tracts' that carry signals between the cerebrum (the top part of the brain) and cerebellum (responsible for coordination and other functions). It also has a role in controlling respiration, heart rate, and and blood pressure and coordinates between the hemispheres of the cerebellum.
- The **midbrain** controls pain by inhibiting pain signals, uses dopamine as part of the mechanisms that control emotion and motor function, is involved in arousal and

174 https://en.wikipedia.org/wiki/Evolution_of_the_brain

175 <https://en.wikipedia.org/wiki/Allometry>

176 <https://www.ebsco.com/research-starters/anatomy-and-physiology/brain-comparative-anatomy>

177 <https://pmc.ncbi.nlm.nih.gov/articles/PMC3606080/>

178 <https://www.sciencedirect.com/topics/computer-science/mammalian-brain>

179 <https://www.ncbi.nlm.nih.gov/books/NBK544297/>

180 <https://en.wikipedia.org/wiki/Brainstem>

consciousness, manages intense alertness and autonomic reflexes, and runs signals between the rest of the brain and the spinal cord.

Cerebellum

The **cerebellum**¹⁸¹ is behind the brain stem (the bundle of nerves at the top of the spinal chord) and below the occipital (back) lobe of the cerebrum. In humans. Its purposes include the coordination of fine sensorimotor tasks, and it may be involved in some cognitive functions, such as language and different motor skills that may involve hands and feet. The cerebellum helps keep equilibrium. In humans, the cerebellum also plays an important role in cognitive functions such as attention, language, and emotional control such as regulating fear and pleasure responses. Similar functions are provided in other animal species. The human cerebellum does not initiate movement, but it contributes to coordination, precision, and accurate timing. It receives input from sensory systems via the brain stem and other brain parts, and integrates them to fine-tune motor activity. It is one of those tightly packed bundles of largely interconnected neurons.

The cerebellum and its auxiliary structures are a composition of several hundred or thousand independently functioning modules called "microzones" or "microcompartments". These appear to be small control systems that fine tune and do real-time control of motor activities based on sensors distributed throughout the body combined with higher level control signals from the cerebral cortex. Communication rates are on the order of 40 signals per second when awake for small amplitude signals and 10 per second for larger amplitude signals, these implemented as spikes traveling along axons to other neurons. There are something like 50 billion of them in humans, all acting asynchronously, for a combined parallel processing signal capacity of perhaps 2 trillion signals per second. Learning behavior is displayed apparently related to the control system features each microzone controls, so each microzone adapts to changes in peripheral physiology it senses and is in control of, essentially tuning the feedback system to the physiology and environmental conditions. This is apparently also part of pain processing and adaptation.

The cerebellum and its mechanisms are present in all classes of vertebrates, including fish, reptiles, birds, and mammals. There are analogous structures in cephalopods and octopuses. It is larger in mammals than birds than reptiles than amphibians and fish. Most vertebrates have a cerebellum and one or more cerebellum-like structures that are involved in sensory processing, but not motor movement.

Thalamus

The **thalamus**^{182 183} is responsible for the relay and filtering of sensory signals from the body to the cerebral cortex. It is also connected to the hippocampus, mammillary bodies, and fornix. It is also involved in learning and episodic memory and regulation of sleep and wakefulness. It has the sensory pathway for pain, temperature and crude touch from the spinal cord which is fed to further fusion and processing with information from the trigeminal nerve about the face. It has different areas associated with arousal and pain regulation, sensory regulation dealing with everything but taste (olfaction) governing motor 'language',

181 <https://en.wikipedia.org/wiki/Cerebellum>

182 <https://en.wikipedia.org/wiki/Thalamus>

183 <https://www.ncbi.nlm.nih.gov/books/NBK542184/>

some mechanisms associated with cognitive functions, and a limbic control area dealing with mood and motivation.

Hypothalamus

The **hypothalamus**^{184 185} links the nervous system to the endocrine system via the pituitary gland. It regulates some metabolic processes and manufactures and secretes hormones that control the pituitary gland. It controls body temperature (including panting, sweating, and shivering), hunger and appetite, aspects of parenting and maternal attachment behaviors, thirst, fatigue, learning, memory, sleep, circadian rhythms, effects heart rate and blood pressure, pupil dilation, and effects social behaviors like sexual and aggressive behaviors. Through the pituitary gland, it regulates various glands and organs including the thyroid gland, adrenal glands, and reproductive organs, and influences growth, fluid balance, and milk production. It connects to many different parts of the brain and fuses and coordinates all of these activities.

Cerebrum

The **cerebrum**^{186 187} is the largest part of the mammalian brain, and includes the cerebral cortex (of the two cerebral hemispheres), the hippocampus, basal ganglia, and olfactory bulb. The cortex contains frontal, precentral, parietal, occipital, and temporal lobes and connectors. It controls emotions, hearing, vision, personality, voluntary actions, and it functions as the center of sensory perception, memory, thoughts, and judgment.

- The **cerebral cortex**¹⁸⁸ is the outer layer of grey matter of the cerebrum and is found only in mammals. In larger mammals, including humans, the surface of the cerebral cortex folds to create gyri (ridges) and sulci (furrows) which increase the surface area. The cerebral cortex is divided by the medial longitudinal fissure into two hemispheres, the right and the left which are connected beneath the cortex by the corpus callosum and other commissural fibers. The right hemisphere controls and processes signals (predominantly) from the left side of the body, while the left hemisphere controls and processes signals (predominantly) from the right side of the body, apparently due to an axial twist early in development. It is generally classified into four lobes: the frontal, parietal, occipital and temporal. A smaller lobe is the insular lobe, a part of the cerebral cortex folded deep within the lateral sulcus that separates the temporal lobe from the parietal and frontal lobes, is located within each hemisphere of the mammalian brain and includes the limbic lobe, and the insular cortex. There are also three lobules of the brain; the paracentral lobule, superior parietal lobule, and inferior parietal lobule.
 - Upper motor neurons in the **primary motor cortex** within the **frontal lobe** have axons to the brain stem and spinal cord to synapses on the lower motor neurons, which innervate the muscles to control voluntary movements of the body.

184 <https://en.wikipedia.org/wiki/Hypothalamus>

185 <https://www.ncbi.nlm.nih.gov/books/NBK535380/>

186 <https://en.wikipedia.org/wiki/Cerebrum>

187 <https://courses.lumenlearning.com/suny-dutchess-anatomy-physiology/chapter/cerebrum/>

188 https://en.wikipedia.org/wiki/Cerebral_cortex

- The cerebrum takes in information from the senses and combines it, so the brain can understand the world as one picture. The main sensory areas notice basic details, while nearby areas put the information together and explain it.
 - The main **visual** area in the **occipital lobe** notices edges, colors, and movement. Nearby areas help the brain recognize objects and faces.
 - The main **auditory** (hearing) area in the **upper temporal lobe** senses the pitch and loudness of sounds. Nearby areas help the brain process more complex sounds like speech and music.
 - The main **touch** (somato) area in the **parietal lobe** maps feelings like touch, pain, temperature, and body position. Each body part has a matching area in the brain, and nearby regions help with spatial awareness and using objects.
 - The brain senses **taste** in the **insula and frontal** areas, then sends this information to the **orbitofrontal cortex**, where flavors are combined and understood.
 - The **olfactory bulb**, responsible for the sense of **smell**, takes up a large area in most vertebrates but is much smaller in humans and lies underneath the **frontal lobe**. Presumably, this is why dogs have a much better sense of smell than people. The sensors in the olfactory bulb send axons directly to the **olfactory cortex** rather than to the thalamus first. Olfaction is also the only sense analyzed by the opposite side of the brain, however, interhemispheric connections allow for bilateral integration of odor information. After this information passes through the olfactory cortex, it is processed in the **orbitofrontal cortex**, which evaluates the identity and the reward value of odors.
- **Multisensory integration** areas in the **parietal and temporal lobes** combine information from different senses to fuse how we see, hear, and act.
- **Speech and language** are attributed to parts of the **cerebral cortex**. Motor portions of language are attributed to Broca's area within the **frontal lobe**. Comprehension is attributed to Wernicke's area, at the **temporal-parietal lobe junction**. These two regions are interconnected by a large white matter tract, the arcuate fasciculus.
- **Memory** of different sorts is located in different places in the brain. The **prefrontal cortex** contributes to "**working memory**" used to describe information relating to problem-solving perhaps including filtering actions according to social norms or ethical and moral consensus, considering outcomes before acting, and planning for the future. Memory has "expiration dates" associated with short, intermediate, and long term memory.
- Brains get more sensory input than they can store and, as discussed earlier in the book, this is a lossy process even with compression. Habituation is used to ignore some signals based on lack of change. In **short-term memory** sensed information can only be retained for a few seconds, possibly extended to a few minutes. **Intermediate-term memory** can result from temporary chemical and physical changes in either presynaptic or postsynaptic membranes that may persist from a few to minutes up to several weeks. Neurotransmitter release is exacerbated by increasing the calcium entry to sensory terminal with the facilitator terminal releasing serotonin activating adenylyl cyclase which forms cyclic adenosine in the main sensory terminal causing the

release of protein kinase; this enzyme in turn phosphorylates the protein that blocks potassium channels in the terminal, decreasing potassium conductance and prolonging the action potential. **Long-term memory** is credited to increase in synaptic vesicles release sites, increase in the vesicles themselves, increase in the synaptic terminals, and change in shape or number of postsynaptic spines, all of which either enhance or suppress signal conduction.

- **Explicit** or declarative (factual) **memory** formation is attributed to the **hippocampus** and associated regions of the **medial temporal lobe**.
- **Implicit** or procedural **memory**, such as **complex motor behaviors**, involves the **basal ganglia**.
- **Short-term or working memory** involves association areas of the cortex, especially the **dorsolateral prefrontal cortex**, as well as the **hippocampus**.
- The **neocortex** is formed of six layers, numbered I (1) to VI (6), from the outermost layer 1, near to the pia mater, to the innermost layer 6, near to the underlying white matter. Each cortical layer has a characteristic distribution of different neurons and their connections with other cortical and subcortical regions. There are direct connections between different cortical areas and indirect connections via the thalamus. One example of cortical layering is the line of Gennari in the primary visual cortex. This is a band of whiter tissue observable with the naked eye in the calcarine sulcus of the occipital lobe. The line of Gennari is composed of axons bringing visual information from the thalamus into layer 4 of the visual cortex.
 - **Layer 1** is the molecular layer that contains few scattered neurons. It consists largely of extensions of apical dendritic tufts of pyramidal neurons and horizontally oriented axons, glial cells, and some spiny stellate cells. Inputs to the apical tufts are thought to be crucial for the feedback interactions in the cerebral cortex involved in associative learning and attention. Layer 1 across the cerebral cortex receives substantial input from matrix or M-type thalamus cells as opposed to core or C-type that go to layer 4. It is thought that layer 1 serves as a central hub for collecting and processing widespread information. It integrates ascending sensory inputs with top-down expectations, regulating how sensory perceptions align with anticipated outcomes. Layer 1 sorts, directs, and combines excitatory inputs, integrating them with neuromodulatory signals. Inhibitory interneurons, within layer 1 and from other cortical layers, gate these signals. Together, these interactions dynamically calibrate information flow throughout the neocortex, filtering sensory input and thus shaping perceptions and experiences.
 - **Layer 2** is the external granular layer containing small pyramidal neurons and numerous stellate neurons. It is thicker during early life, but regresses as the individual gets older until it essentially disappears by maturity.¹⁸⁹
 - **Layer 3** is the external pyramidal layer, containing predominantly small and medium-size pyramidal neurons and non-pyramidal neurons with vertically oriented intracortical axons. Layers 1-3 are the main target of commissural corticocortical

189 [https://en.wikipedia.org/wiki/External_granular_layer_\(cerebral_cortex\)](https://en.wikipedia.org/wiki/External_granular_layer_(cerebral_cortex))

afferents (left to right and right to left hemisphere paths), and layer 3 is the principal source of corticocortical efferents (between parts of the same hemisphere).

- **Layer 4**, the internal granular layer, contains different types of stellate and pyramidal cells, and is the main target of thalamocortical afferents from thalamus type C neurons (core-type) and intra-hemispheric corticocortical afferents. The layers above layer 4 are also referred to as supragranular layers while the layers below are referred to as infragranular layers. African elephants, cetaceans, and hippopotamus do not have a layer 4 with axons which would terminate there, going instead to the inner part of layer 3.
- **Layer 5**, the internal pyramidal layer, contains large pyramidal neurons. Axons from these leave the cortex and connect with subcortical structures including the basal ganglia. In the primary motor cortex of the frontal lobe, layer 5 contains giant pyramidal cells called Betz cells, whose axons travel through the internal capsule, the brain stem, and the spinal cord forming the corticospinal tract, which is the main pathway for voluntary motor control.
- **Layer 6**, the polymorphic or multiform layer, contains few large pyramidal neurons and many small spindle-like pyramidal and multiform neurons. Layer 6 has efferent fibers to the thalamus with layer 6 neurons from the same cortical columns connected with the same thalamus neurons providing input. These connections are both excitatory and inhibitory, or in other words, form a control system wherein cortical columns control thalamus neurons associated with specific sensory inputs, essentially providing set points for more precise brain stem control of trigger levels for reflexes and action thresholds for detection. We feel what we want to feel.

Examples of neocortical areas include the granular primary motor cortex, and the striate primary visual cortex. The neocortex has two subtypes, the true isocortex and the proisocortex which is a transitional region between the isocortex and the regions of the periallocortex.

- The much smaller area of allocortex that has three or four layers and has three subtypes, the paleocortex with three cortical laminae, the archicortex which has four or five, and a transitional area adjacent to the allocortex, the periallocortex. Examples of allocortex are the olfactory cortex and the hippocampus. There is a transitional area between the neocortex and the allocortex called the paralimbic cortex, where layers 2, 3 and 4 are merged. This area incorporates the proisocortex of the neocortex and the periallocortex of the allocortex.

Mammals have cerebellums with larger lateral lobes that interact with the neocortex,¹⁹⁰ a set of layers of the mammal brain dealing with sensory perception, cognition, generation of motor commands, spatial reasoning, and language. As monkeys evolved into great apes, the lateral lobes expanded along with the frontal lobes of the neocortex.

Hopefully some of my readers have followed carefully enough to notice that the descriptions of the mechanisms of the central nervous system are less complex than for other systems of the body. That's not because I have been ignoring the details, it's because, as far as I can tell, they haven't been figured out yet. There are many folks working on it, and eventually I think

190 <https://en.wikipedia.org/wiki/Neocortex>

the science will become reasonably complete about all of the control mechanisms of the central nervous system, and we will finally understand the mechanisms of thought. But what seems apparent to me is that the brain is a cybernetic system like other cybernetic systems of the body, with complex interacting control systems using sensors to communicate to control mechanisms that communicate to trigger actions and using feedback mechanisms to retain control. Complicated? Very! But finite, and eventually understandable in detail, with the same sorts of capabilities and limitations of all cybernetic systems. It is clearly a critical infrastructure for vertebrates, controlling transportation within the body and movement of the body, but other than electrical signals, it doesn't "transport" anything itself, although during deep sleep, interstitial spaces expand, changing the flow of cerebrospinal fluid, and the brain flushes waste products.¹⁹¹

Digestive system

The Digestive System:¹⁹² Breaks down food into compounds to fuel metabolism. Vertebrates have mouths and throats to ingest, stomachs and intestines to digest, anuses or cloacas to excrete waste, and organs (e.g., liver and pancreas) that secrete digestive enzymes that break down the food. The cerebral cortex (motor areas) initiates voluntary chewing and initial ingest, with sensory input from the mouth as feedback. The throat is controlled by the medulla oblongata for involuntary swallowing and coordinated by it for voluntary (cerebral cortex driven) swallowing. Internal organs of digestion are controlled by the autonomic nervous system.

- Mammalian digestive systems use ruminants (cows, sheep) for fermenting cellulose (rumen, reticulum, omasum, abomasum) and large hindguts in hindgut fermenters (horses, rabbits) for microbial breakdown, while carnivores like cats have simpler, shorter tracts suited for meat.¹⁹³
- The human digestive system consists of the gastrointestinal tract and other organs of digestion (the tongue, salivary glands, pancreas, liver, and gallbladder). Digestion involves the breakdown of food into smaller and smaller components, until they can be absorbed and assimilated into the body. The process of digestion has three stages: the cephalic phase, the gastric phase, and the intestinal phase.
 - The **cephalic phase** begins with secretions from gastric glands in response to the sight and smell of food, and continues in the mouth with the mechanical breakdown of food by chewing by the muscles of mastication, the tongue, the teeth, the contractions of peristalsis, simultaneous with chemical breakdown by digestive enzymes in the saliva which contains amylase and lingual lipase secreted by salivary glands and serous glands on the tongue. Chewing mixes food with saliva to produce a swallow-able bundle moved down the esophagus to enter the stomach.
 - The **gastric phase** in the stomach breaks down food by mixing it with gastric juice until it passes into the duodenum, the first part of the small intestine. Gastric juice containing gastric acid, and the production of mucus in the stomach, are essential

191 <https://medicine.washu.edu/news/neurons-help-flush-waste-out-of-brain-during-sleep/>

192 https://en.wikipedia.org/wiki/Human_digestive_system

193 <https://en.wikipedia.org/wiki/Mammal>

for the continuation of digestion. Within its mucosa are millions of embedded gastric glands. Their secretions as gastric juice are vital to the functioning of the organ.

- The **intestinal phase** mixes partially digested food with pancreatic digestive enzymes to complete digestion. Most digestion of food is in the small intestine, the longest part of the GI tract but with smaller diameter than the large intestine. The largest part of the GI tract is the large intestine with the colon as the main functional unit, absorbing water and forming and storing remaining waste prior to defecation.
- **Peristalsis** is a rhythmic contraction of muscles in the esophagus, along the wall of the stomach, and through the rest of the gastrointestinal tract. This initially results in the production of chyme which when fully broken down in the small intestine is absorbed as chyle into the lymphatic system. Most of the digestion of food takes place in the small intestine. Water and some minerals are reabsorbed back into the blood in the large intestine. The waste products of digestion (feces) are excreted from the rectum via the anus. Organs involved in digestion outside of the gastrointestinal (GI) tract are called accessory digestive organs and include the mouth, tongue, and glandular organs, the salivary glands, liver, gall bladder, and pancreas. Other components considered are the teeth and epiglottis. A number of sphincters¹⁹⁴ in the GI tract are also involved in digestion, including those of the esophagus (esophageal sphincters) and stomach (pyloric sphincter).
- The **mouth** is the entry point for food in the upper gastrointestinal tract. It has several structures that begin the first processes of digestion, including salivary glands, teeth, and the tongue which has taste receptors to differentiate food desirability. The mouth has two regions; the vestibule between the teeth, lips and cheeks; and the rest is the oral cavity which is lined with oral mucosa, a mucous membrane producing lubricating mucus, which is viscous, clear, and clinging, secreted by surface cells or glands and containing a glycoprotein called mucin of a type varying based on location.
 - Under the mucous membrane is a thin layer of smooth muscle tissue providing elasticity. This coating covers the cheeks, inner surfaces of the lips, and floor of the mouth, and the mucous also protects against tooth decay. The roof of the mouth (the palate) separates the oral cavity from the nasal cavity, is hard at the front of the mouth, the mucous covering a bone, and softer and more pliable at the back, made of muscle and connective tissue. It ends at the uvula and can move to swallow food and liquids. The surface of the hard palate provides pressure for eating food leaving the nasal passage clear. The opening between the lips (the oral fissure) and the opening into the throat (the fauces) are the entry and exit for food, or exit and entry for vomiting (emesis).
 - At either side of the soft palate palatoglossus muscles reach into the tongue to raise the back of the tongue and close the sides of the fauces to enable swallowing. Mucus helps in the mastication of food in its ability to soften and collect the food in the formation of the bolus.
 - There are three pairs of **main salivary glands** and between 800 and 1,000 minor salivary glands, all mainly serving the digestive process and maintaining dental health and mouth lubrication, and without which speech would be impossible. The

194 A ring of muscle surrounding and serving to guard or close an opening or tube.

main glands are exocrine glands, secreting via ducts that terminate in the mouth. The largest are the parotid glands secreting serous, underneath the jaw the submandibular glands produce both serous fluid and mucus, the serous fluid produced by serous glands within the salivary glands which also produce lingual lipase. The third pair are the sublingual glands located underneath the tongue that secrete mucus and a small percentage of saliva.

- Within the oral mucosa, on the tongue, palates, and floor of the mouth, are **minor salivary glands** secreting mainly mucus and innervated by the facial nerve. The glands also secrete amylase, a compound acting on carbohydrate in food to turn starch into maltose. Other serous glands on the tongue encircle taste buds on the back part of the tongue and produce lingual lipase, a digestive enzyme that catalyses the hydrolysis of lipids (fats). These glands also secrete histatins that are an early defense (outside of the immune system) against microbes in food that makes contact with them on tongue tissue. Sensory information can stimulate saliva secretion providing fluid for the tongue and easing swallowing.
- **Saliva** moistens and softens food, and with chewing action of the teeth, transforms food into a smooth bolus further helped by saliva lubrication in its passage into the esophagus. Saliva also has digestive enzymes amylase and lipase. Amylase breaks down starch in carbohydrates into simple sugars (maltose and dextrose) further broken down in the small intestine. Lipase breaks down fats and is also produced in the pancreas and released to continue digestion of fats. Saliva also has a cleansing action for the teeth and mouth and an immunological role in supplying antibodies like immunoglobulin A preventing salivary gland infections, and it contains a glycoprotein called haptocorrin that binds to vitamin B12 to carry it safely through the acidic content of the stomach through to the pancreas.
- **Taste and smell** is a form of chemoreception from specialized taste receptors in taste buds in the mouth, mainly on the upper surface (dorsum) of the tongue. Taste is vital to prevent harmful or rotten foods from being consumed. There are also taste buds on the epiglottis and upper part of the esophagus. Taste buds are innervated by a branch of the facial nerve (the chorda tympani), and the glossopharyngeal nerve. Taste messages go via these cranial nerves to the brain which can distinguish chemical qualities of food. The five basic tastes are saltiness, sourness, bitterness, sweetness, and umami. Saltiness and sourness enable control of salt and acid balance. Bitterness warns of poisons, particularly from plant defenses. Sweetness identifies foods with high energy with initial breakdown of carbohydrates by salivary amylase creating a sweet taste from the resulting simple sugars. Umami is thought to signal protein-rich food. Sour tastes are acidic and often found in bad food. The brain has to decide quickly whether the food should be eaten or not. The olfactory receptors located on cell surfaces in the nose bind to chemicals enabling the detection of smells and it is assumed that signals from taste and nose combine to form complex food flavors.
- **Teeth** are complex structures made of a bone-like material called dentin, which is covered by the hardest tissue in the body, enamel. Teeth have different shapes to deal with different aspects of mastication (tearing and chewing) of pieces of food into smaller and smaller pieces resulting in a much larger surface area for actions

of digestive enzymes. Incisors cut to bite off pieces of food, canines tear, and premolars and molars chew and grind.

- The **epiglottis** is a flap of elastic cartilage attached to the entrance of the larynx, covered with a mucous membrane and with taste buds on its lingual surface (facing into the mouth) and its laryngeal surface facing the larynx. It guards the entrance of the glottis, the opening between the vocal folds. It is normally pointed upward during breathing, but during swallowing it folds down to prevent food from going into the trachea, directing it to the esophagus. Swallowing, the backward motion of the tongue forces the epiglottis over the glottis opening to prevent food from entering the larynx. Stimulation of the larynx by ingested matter produces a strong cough reflex to protect the lungs.
- The **pharynx** is part of the conducting zone of the respiratory system and of the digestive system. It is immediately behind the nasal cavity at the back of the mouth and above the esophagus and larynx, and is made up of three parts; the lower two parts (oropharynx and laryngopharynx) split to serve the digestive and respiration systems while the thearyngopharynx is a passageway for air and food. Swallowing has priority and air is temporarily blocked. The pharynx is innervated by the pharyngeal plexus of the vagus nerve and muscles in the pharynx push food into the esophagus. The pharynx joins the esophagus at the oesophageal inlet which is located behind the cricoid cartilage.
- The **esophagus** (foodpipe or gullet) consists of a muscular tube that passes food from pharynx to stomach, it is continuous with the laryngopharynx, and passes through the posterior mediastinum in the thorax to enter the stomach through a hole in the thoracic diaphragm (the esophageal hiatus). It is divided into cervical, thoracic, and abdominal parts. At rest it is closed at both ends by sphincters. The upper sphincter is triggered by the swallowing reflex so food passes through, and prevents back flow when closed. The epiglottis folds down to direct food into the esophagus and away from the trachea. Once in the esophagus, the bolus travels to the stomach via rhythmic contraction and relaxation of peristalsis muscles. The lower esophageal sphincter surrounds the lower part of the esophagus and remains constricted other than during swallowing and vomiting. A failure of this sphincter can lead to heartburn.
- The **diaphragm** separates the thoracic from the abdominal cavity where most of the digestive organs reside. A suspensory muscle attaches duodenum to diaphragm and is thought to ease passage of digesting material. The diaphragm also attaches to and anchors the liver at its bare area.
- The **stomach** is a distensible organ that expands to hold about one litre of food, enabled by gastric folds in its inner walls. It is a J-shaped organ joined to the esophagus at its upper end and to the duodenum at its lower end. Gastric acid produced in the stomach contains hydrochloric acid and sodium chloride. A peptide hormone (gastrin) produced by G cells in the gastric glands stimulates production of gastric acids that activate the enzyme pepsin which begins digestion of proteins. Mucus secreted by gastric glands in the stomach provide a slimy protective layer against the chemicals on the inner layers of the stomach. As protein is being digested, waves of muscular contractions that move along the stomach wall cause churning to

increase mixing with digestive enzymes. Gastric lipase secreted by fundic glands in the gastric mucosa is an acidic lipase that breaks fats down and alkaline pancreatic lipase finishes the job. The lowest part of the stomach (pylorus) attaches to the duodenum via the pyloric canal and contains glands that secrete digestive enzymes including gastrin. After a few hours a thick semi-liquid called chyme is produced, and when the pyloric sphincter opens, the chyme enters the duodenum where it mixes with digestive enzymes from the pancreas, and then passes through the small intestine, where digestion continues. The parietal cells in the fundus produce a glycoprotein (intrinsic factor) essential for absorption of vitamin B12 that was bound to a glycoprotein secreted by the salivary gland in the mouth. Once freed it binds to intrinsic factor then absorbed by the enterocytes in the ileum.

- The **spleen** is the largest lymphoid organ in the body and also breaks down broken red and white blood cells, sends bilirubin produced in digestion to the liver for secretion in bile, and sends iron used to form new blood cells to bone marrow. The spleen belongs to the lymphatic system as well, but all of its functions are not yet understood.
- The **liver** (the second largest organ after the skin) is an accessory digestive gland which plays a role in the body's metabolism and has many non-digestion functions like detoxifying metabolites, synthesizing proteins, and producing biochemicals used in digestion. It regulates storage of glycogen it forms from glucose and can also synthesize glucose from amino acids. In digestion it breaks carbohydrates down and maintains protein metabolism in its synthesis and degradation. In lipid metabolism it synthesizes cholesterol, produces fats in lipogenesis, makes most lipoproteins, and makes bile acids and lecithin to digest fat. It's attached to the diaphragm to the right of the stomach and atop the **gall bladder**.
- **Bile** produced by the liver lowers the surface tension and helps to emulsify fats in the chyme. Food fat is dispersed by bile into smaller micelles creating a larger surface area for the pancreatic enzyme lipase to process. Lipase digests the triglycerides into two fatty acids and a monoglyceride that are then absorbed by villi on the intestinal wall. Bile also helps the absorption of vitamin K from the diet. It is collected and delivered through the common hepatic duct that joins with the cystic duct into a common bile duct with the **gallbladder** where bile is stored for release when food is discharged into the duodenum.
- The **gallbladder** is a hollow part of the biliary tract just beneath the liver. It's a small organ where the bile produced by the liver is stored, before being released into the small intestine. It is divided into three sections, a **fundus**, **body**, and **neck**. The neck tapers and connects to the biliary tract via the cystic duct, which joins the common hepatic duct to form the common bile duct. At this junction is a mucosal fold (Hartmann's pouch) where gallstones commonly get stuck. The muscular layer of the **body** is of smooth muscle tissue that helps the gallbladder contract, so it can discharge its bile into the bile duct. The gallbladder needs to store bile in a natural, semi-liquid form at all times. Hydrogen ions secreted from the inner lining keep the bile acidic enough to prevent hardening while water and electrolytes from digestion dilute the bile. Salts attach themselves to cholesterol molecules in bile to keep them from crystallizing into gallstones. The main purpose of the gallbladder is to store and release bile (gall) which helps the small intestine digest fats by breaking down larger molecules

into smaller ones. After the fat is absorbed, the bile is also absorbed and transported back to the liver for reuse.

- The **pancreas** functions as an accessory digestive gland and is an endocrine gland and an exocrine gland. The endocrine part secretes insulin when the blood sugar becomes high to move glucose from blood to muscles and other tissues for use as energy and releases glucagon when the blood sugar is low to allow stored sugar to be broken down into glucose by the liver to re-balance the sugar levels. The pancreas also produces and releases digestive enzymes in the pancreatic juice to the duodenum via the pancreatic duct which it joins near to the bile duct where both bile and pancreatic juice act on the chyme released from the stomach. Aqueous pancreatic secretions contain alkaline bicarbonate ions to help bile to neutralise the acidic chyme churned out by the stomach. The pancreas is also the main source of enzymes for digestion of fats and proteins. The cells are filled with secretory granules containing precursor digestive enzymes which work on proteins.
- The **lower gastrointestinal (GI) tract** includes the small and large intestine. The lower GI tract starts at the pyloric sphincter of the stomach and finishes at the anus.
 - The **small intestine** is subdivided into the **duodenum**, **jejunum** and **ileum**. Partially digested food arrives in the small intestine as very acidic semi-liquid chyme where pH is balanced to activate digestive enzymes in the duodenum by adding bile from the gall bladder, bicarbonate secretions from the pancreatic duct, and secretions of bicarbonate-rich mucus from duodenal glands. When the food particles are reduced enough in size and composition, they are absorbed by the intestinal wall and into the bloodstream. Segmentation contractions mix and move chyme through the small intestine allowing time for absorption
 - This starts with chyme at the duodenal bulb and ends at the suspensory muscle of **duodenum**. Pancreatic lipase is secreted to digest fat content, then smaller particles of emulsified fats (chylomicrons) are produced. Digestive cells (enterocytes) lining the intestines have villi on their surface which have microvilli on their surface to create large surface area for the absorption of chyme and digestion by large numbers of digestive enzymes on the microvilli. The chylomicrons are small enough to pass through the enterocyte villi and into their lymph capillaries (lacteals). A milky fluid (chyle) consisting mainly of the emulsified fats of the chylomicrons results from the absorbed mix with the lymph and is transported through the lymphatic system to the rest of the body.
 - The suspensory muscle divides the duodenum from the **jejunum** that contains circular folds (flaps of doubled mucosal membrane that encircle the lumen of the intestine) that, together with villi increase the surface area of the jejunum for increased absorption of digested sugars, amino acids, and fatty acids into the bloodstream and slow the passage of food increasing time to absorb nutrients.
 - The last part of the small intestine is the **ileum**, which also contains villi and vitamin B12, and where bile acids and residue nutrients are absorbed. When the chyme is exhausted of nutrients remaining waste changes into semi-solids (feces) which pass to the large intestine where bacteria in the gut flora break down residual proteins and starches.

Transit time through the small intestine is an average of 4 hours. Half of the food residues of a meal have emptied from the small intestine by an average of 5.4 hours after ingestion. Emptying of the small intestine is complete after an average of 8.6 hours, about 9 hours after food enters the system.

- The **cecum** is a pouch dividing the small and large intestine. It lies below the ileocecal valve in the lower right quadrant of the abdomen and receives chyme from the last part of the small intestine (ileum) connecting to the ascending colon of the large intestine through a sphincter (ileocecal valve) which slows chyme going from the ileum allowing further digestion and is the attachment site for the **appendix**. The **colon** supports fermentation by the gut flora.
- The **large intestine** includes the rectum and anal canal. In the large intestine food takes from 30 to 40 hours before remaining semi-solid waste is termed feces and is removed by coordinated contractions of intestinal walls (peristalsis) propelling the excreta toward the rectum for anal exit (defecation). The wall has an outer layer of longitudinal muscles, the taeniae coli, and an inner layer of circular muscles. The circular muscle keeps material moving forward and prevents waste back flow. The basal electrical rhythm determines the frequency of contractions. The taeniae coli are responsible for the bulges (haustra) present in the colon and most parts of the GI tract are covered with serous membranes and have a mesentery while more muscular parts are lined with adventitia.
- The digestive system is supplied by the **celiac artery**, the first major branch from the abdominal aorta with three main divisions; the left gastric artery, the common hepatic artery, and the splenic artery.
 - The **celiac artery** supplies the liver, stomach, spleen, top 3rd of the duodenum (to the sphincter of Oddi), and pancreas with oxygenated blood. Most of the blood is returned to the liver via the portal venous system for further processing and detoxification then returned to systemic circulation via hepatic veins.
 - The **superior mesenteric artery** supplies the digestive tract from the midgut, including the distal 2/3 of the duodenum, jejunum, ileum, cecum, appendix, ascending colon, and the proximal 2/3 of the transverse colon.
 - The **inferior mesenteric artery** supplies the digestive tract from the hindgut, including the distal 1/3 of the transverse colon, descending colon, sigmoid colon, rectum, and the anus above the pectinate line.
- The **enteric nervous system** has ~100,000,000 neurons embedded in the lining of the gastrointestinal tract (peritoneum) extending from the esophagus to the anus. They are collected in the myenteric (Auerbach's) plexus that lies between the longitudinal and the smooth muscle layers, and the submucosal (Meissner's) plexus that lies between the circular smooth muscle layer and the mucosa. Parasympathetic innervation to the ascending colon is supplied by the vagus nerve. Sympathetic innervation is supplied by the splanchnic nerves that join the celiac ganglia. Most of the digestive tract is innervated by the two large celiac ganglia, with the upper part of each ganglion joined by the greater splanchnic nerve and the lower parts joined by the lesser splanchnic nerve. It is from these ganglia that many of the gastric plexuses arise.

The digesting system includes a wide range of transportation and manufacturing mechanisms as an infrastructure that supplies nutrients and eliminates waste from the body. They include automatic and brain operated controls and overrides, and a wide range of chemical and cellular processes that manufacture the materials needed for digestion and deliver them through blood and lymph to the digestive system and deliver waste from the system. As a complex control system, they are about as complicated as I have seen, and far more complex than any human built control systems to date.

Endocrine system

The Endocrine System:¹⁹⁵ Made up of glands that secrete hormones directly into interstitial spaces where they are absorbed into blood rather than through a duct. They influence or control metabolism, growth, and reproduction. This system is largely controlled by the hypothalamus via the pituitary gland and is a messenger system comprising feedback loops of hormones released by internal glands directly into the circulatory system that target and regulate distant organs. The major glands of the endocrine system are the pineal gland, pituitary gland, pancreas, ovaries, testes, thyroid gland, parathyroid gland, hypothalamus and adrenal glands. The hypothalamus and pituitary gland are neuroendocrine organs mediating important feedback loops.

- Glands that signal each other in sequence are often referred to as an **axis**, such as the **hypothalamic–pituitary–adrenal axis**. In addition to specialized endocrine organs, many other organs have secondary endocrine functions, including bone, kidneys, liver, heart and gonads. Hormones can be amino acid complexes, steroids, eicosanoids, leukotrienes, or prostaglandins.
- In humans, the major endocrine glands are the thyroid, parathyroid, pituitary, pineal, and adrenal glands, and the (male) testis and (female) ovaries. The hypothalamus, pancreas, and thymus also function as endocrine glands, among other functions. The hypothalamus and pituitary glands are organs of the neuroendocrine system. One of the most important functions of the hypothalamus (located in the brain adjacent to the pituitary gland) is to link the endocrine system to the nervous system via the pituitary gland. Other organs, like the kidneys, also have roles within the endocrine system by secreting hormones. The thyroid secretes thyroxine, the pituitary secretes growth hormone, the pineal secretes melatonin, the testis secretes testosterone, and the ovaries secrete estrogen and progesterone.
- The **hypothalamus** is a key regulator of the autonomic nervous system. It has three sets of endocrine outputs; the magnocellular system, the parvocellular system, and autonomic intervention. The magnocellular is involved in the expression of oxytocin or vasopressin. The parvocellular is involved in controlling the secretion of hormones from the anterior pituitary.
- The **pituitary gland** includes **anterior** and **posterior** parts. The anterior pituitary gland produces and secretes tropic hormones. The posterior pituitary gland stores and secretes hormones like antidiuretic hormone (ADH) synthesized by supraoptic nucleus of hypothalamus and oxytocin (synthesized by paraventricular nucleus of the hypothalamus). ADH helps the body to retain water and is important in maintaining a

¹⁹⁵ https://en.wikipedia.org/wiki/Endocrine_system

homeostatic balance between blood solutions and water. Oxytocin functions to induce uterine contractions, stimulate lactation, and allows for ejaculation.

- Follicular cells of the **thyroid** gland produce and secrete T3 and T4 in response to elevated levels of TRH produced by the hypothalamus, and subsequent elevated levels of TSH produced by the anterior pituitary gland, which further regulates metabolic activity and rates of all cells, including cell growth and tissue differentiation.
- The endocrine system can control all emotions and can control temperature. Epithelial cells of the **parathyroid** glands are supplied with blood from the inferior and superior thyroid arteries and secrete parathyroid hormone (PTH) that acts on bone, the kidneys, and the GI tract to increase calcium reabsorption and phosphate excretion; and stimulates the conversion of Vitamin D to its most active variant D3, which further stimulates calcium absorption in the GI tract.
- The **pancreas** contains 1 to 2 million islets of Langerhans (a tissue of cells that secrete hormones) and acini. Acini secretes digestive enzymes. **Alpha** pancreas cells secrete hormones to maintain homeostatic blood sugar. Insulin is produced and excreted to lower blood sugar to normal levels. Glucagon is secreted in response to low blood sugar levels and stimulates glycogen stores in the liver to release sugar. **Beta** cells secrete insulin that decreases blood glucose level. And there are many other types of cells involved in different systemic control loops.
- A **hormone** is a class of signaling molecules transported by the circulatory system to target distant organs to regulate physiology and behaviour. They have diverse chemical structures, mainly of 3 classes: eicosanoids, steroids, and amino acid/protein derivatives (amines, peptides, and proteins). The term is sometimes extended to include same cell (autocrine or intracrine) or nearby cells (paracrine) signalling.
 - **Hormones** are used to communicate between organs and tissues for physiological regulation and behavioral activities, such as digestion, metabolism, respiration, tissue function, sensory perception, sleep, excretion, lactation, stress, growth and development, movement, reproduction, and mood. They bind to specific receptor proteins in target cells to change cell function. Cell type-specific responses include rapid changes in protein activity, or slower changes in expression of target genes. Amino acid-based hormones (amines and peptide or protein hormones) are water-soluble and act on target cell surfaces via transduction pathways. Steroids are lipid-soluble and move through target cell plasma membranes to act within their nuclei.
- The typical mode of **cell signaling** in the endocrine system is using the circulatory system to reach distant target organs. However, there are also other modes, i.e., paracrine, autocrine, and neuroendocrine signaling.
 - **Autocrine** signaling is when cells secrete a hormone or chemical messenger (autocrine agent) that binds to autocrine receptors on the same cell, leading to changes in the cells.
 - **Juxtacrine** signaling is transmitted via oligosaccharide, lipid, or proteins of cell membranes and may effect emitting or immediately adjacent cells. It occurs between adjacent cells with broad areas of closely opposed plasma membrane linked by transmembrane channels known as connexons.

- **Paracrine** signaling is the pancreatic path through the blood stream.

The endocrine system is essentially a set of systemic feedback control systems maintaining desired normal conditions in the body through glandular manufacturing and blood transport of chemicals using the circulatory system as infrastructure.

Reproductive system

The Reproductive System:¹⁹⁶ Enables animals to create offspring. Vertebrates have gonads, paired organs that create sperm (in males) and eggs (in females). Males have penises, and females have vaginas, milk-secreting nipples, and wombs for fetus gestation. These systems are largely effected by hormones through the endocrine system controlled by the hypothalamus, and musculature controlled by the brain stem for motor output, limbic system¹⁹⁷ (amygdala and temporal lobes) for emotion, and frontal and orbitofrontal cortex for complex behaviors with signals passed through the spinal chord for actuation and sensing. While some of these mechanisms are systemic passed through the blood stream, they may only activate specific local mechanisms, and the muscular controls are specific to the body parts effected.

It is important to note that, in this sense, the 'reproductive system' is about reproduction of the entire phenotype, but in addition, internal to each phenotype there are many cells and other structures that are reproducing and reassembling in enormous volume all the time. The components reproduce as well as the composite phenotype.

Lymphatic system

The Lymphatic System:¹⁹⁸ A body-wide network of lymph nodes which secrete and circulate a clear fluid called lymph that is virtually identical to blood, but lacks red blood cells and contains a slight excess of white blood cells. It keeps the circulatory system supplied with the plasma component of blood and maintains the immune system. Lymph originates in the interstitial fluid that leaks from blood in the circulatory system into the tissues of the body. This fluid carries nutrients to the cells and collects waste products, bacteria, and damaged cells, then drains into the local lymphatic vessels as lymph.

- The circulatory system processes an average of 20 litres (5.3 US gal) of blood per day through capillary filtration, which removes plasma from the blood. Roughly 17 litres (4.5 US gal) of the filtered blood is reabsorbed directly into the blood vessels. The remaining 3 litres (0.79 US gal) are left in the interstitial fluid. The lymphatic system provides an accessory return route to the blood for this remainder, or in other words, it is another internal transportation system.
- Lymph nodes filter out unwanted materials such as bacteria and damaged cells. Lymph then passes into much larger lymph ducts that drain into the subclavian veins to return to the blood circulation. Lymph is moved through the system by muscle contractions or in some vertebrates with a separate lymph heart. The right lymphatic duct drains the right side of the body and the much larger left lymphatic duct, known as

196 https://en.wikipedia.org/wiki/Reproductive_system

197 https://en.wikipedia.org/wiki/Limbic_system

198 https://en.wikipedia.org/wiki/Lymphatic_system

the thoracic duct, drains the left side of the body. The spleen¹⁹⁹ removes old red blood cells, holds a reserve of blood, and recycles iron. The thymus²⁰⁰ manufactures and matures T cells to adapt the immune system to detected invaders found in the lymph. The palatine tonsils and adenoid tonsil²⁰¹ process lymph and support the development of immunologic memory. They harbor microbial communities and antigen-presenting cells and act as a first line of defense against inhaled or ingested pathogens.

- Lymph cells including T cell precursors, B cells, are produced and B cells matured by bone marrow. B cells directly enter the circulatory system while T-cells go through the thymus and become matured and specialized based on pathogens detected. There are hundreds of lymph nodes in the typical body, and lymphatic capillaries and vessels serve as pathways for lymph transportation, capillaries providing paths from tissues into the lymphatic system and vessels to propel absorbed fluids to collecting ducts. They contain valves to limit flow direction, and muscles combine with other pressure to move fluids through the system.
- Finally, when cancer or other diseases spread through the lymphatic system, they reach the entire body in a similar manner to how blood can spread diseases. Once cancers hit lymph nodes, if they survive, they tend to spread systemically.

Muscular system

The Muscular System:²⁰² Tissues that allow movement. There are 3 main components; skeletal (to move body parts), smooth (for breathing and digestion and not under conscious control), and cardiac (power the circulatory system).

- **Skeletal muscle** (actuators) are invoked by conscious control and managed at a lower level by the cerebellum for fine motor control. In large vertebrates, muscle comprises half or more of their body, and in sharks, about 85%. They are attached to skin or bones and operate in parallel as long forms in groups. Nerve cells stimulate muscles which contract and release. The cells shorten and thicken causing the ends to get closer, pulling on whatever they connect to. This takes about 10 milliseconds in eyes, and longer for larger muscles in other places.
- **Smooth muscle** (actuators) are invoked by the autonomic nervous system, hormones, and local chemical signals, allowing for gradual and sustained contractions. This type of muscle tissue is also capable of adapting to different levels of stretch and tension, which is important for maintaining proper blood flow and the movement of materials through the digestive system. They are very small, on the order of 8 microns wide and 30-100 microns long (1/10 of a millimeter). They can remain contracted for long periods and consume very little energy. They are arranged as functional units with many cells connected to each other by gap junctions that allow contraction from cell to cell similar to cardiac muscle so when one cell begins to contract, a wave of contraction spreads throughout the network.

199 <https://en.wikipedia.org/wiki/Spleen>

200 <https://en.wikipedia.org/wiki/Thymus>

201 <https://en.wikipedia.org/wiki/Tonsil>

202 <https://www.ebsco.com/research-starters/anatomy-and-physiology/muscles-vertebrates>

- **Cardiac muscle** (actuators) are invoked by autonomic signals sequenced from the medulla oblongata and are not under control except to the extent that they can be hastened or slowed by stress levels and similar mechanisms that call for more oxygen. The heart internally controls sequencing without the need for neural or hormonal stimuli, similar to other smooth motor cells with networked operational modalities. The vagus nerve can reduce the high-frequency component of heart rate and innervates smooth muscle cells in other organs as well, largely apparently to reduce abnormal conditions cause by various diseases and failure modes.²⁰³

Immune system

The Immune System:²⁰⁴ Responsible for distinguishing an animal's native tissues from foreign bodies and pathogens like viruses, bacteria, and parasites. Also responsible for mobilizing immune responses, where cells, proteins, and enzymes are manufactured by the body to destroy invaders. The main carrier of the immune system is the lymphatic system. Immune systems are layered defenses including physical barriers (including skin, cell walls, and outer edges of internal structures) that prevent entry of pathogens, the innate immune system that provides immediate non-specific response, and the adaptive immune system activated by the innate response. During an infection, the immune system adapts to improve recognition of the pathogen and retains memory of the response after the pathogen has been eliminated to support faster and stronger responsive attacks on the pathogen in subsequent encounters. These responses depend on the ability to distinguish self from non-self (anomaly detection).

- **Barriers:** Organisms act to protect body openings required for feeding, waste elimination, and sensations. Lungs cough and sneeze to mechanically eject pathogens and irritants from the respiratory tract. Tears and urine mechanically expel pathogens, and mucus secreted by the respiratory and gastrointestinal tract traps and entangles microorganisms. The skin and respiratory tract secrete antimicrobial peptides, enzymes in saliva, tears, and breast milk are also antibacterials, vaginal secretions form a chemical barrier when they become slightly acidic, while semen uses zinc to kill pathogens. Stomachs have high acidity that kills many invaders, while commensal flora act as biological barriers by competing with pathogenic bacteria for food and space and, in some cases, changing environmental conditions such as pH or available iron. These are control systems that block, expel, or change conditions for defense in direct response to identified conditions without recognition.
- **Innate response:** Innate response is usually triggered when microbes are identified by pattern recognition receptors recognizing known bad components or damaged, injured, or stressed cells that send out alarm signals matching known patterns of pathogens. Innate defenses are non-specific, responding in a generic way. It is the dominant system of host defense in most organisms and the only one in plants. They are proteins expressed, mainly, by cells of the innate immune system, such as dendritic cells, macrophages, monocytes, neutrophils, and epithelial cells to identify two classes of molecules: pathogen-associated molecular patterns (PAMPs) associated with microbial pathogens, and damage-associated molecular patterns (DAMPs) associated

203 <https://pmc.ncbi.nlm.nih.gov/articles/PMC6996447/>

204 https://en.wikipedia.org/wiki/Immune_system

with components of host cells released during cell damage or death. Recognition triggers synthesis and secretion of cytokines and activation of other host defense mechanisms necessary for both innate or adaptive immune responses. Some leukocytes (white blood cells) act like independent, single-celled organisms and are the second arm of the innate immune system. The innate leukocytes identify and eliminate pathogens, either by attacking larger pathogens through contact or by engulfing and then killing microorganisms.

- Phagocytes that engulf pathogens or particles patrol the body hunting pathogens, but can be called to specific locations by cytokines. Once a pathogen is engulfed by a phagocyte, it becomes trapped in an intracellular vesicle, it fuses with another vesicle, and the pathogen is killed by digestive enzymes or following a respiratory burst that releases free radicals. Neutrophils and macrophages are phagocytes that travel in pursuit of invading pathogens. Neutrophils travel through the bloodstream, migrate toward the inflammation and are usually the first cells to arrive at the scene of infection. Macrophages reside within tissues and produce chemicals including enzymes, complement proteins, and cytokines. They also act as scavengers that rid the body of worn-out cells and other debris and activate the adaptive immune system. Dendritic cells are phagocytes in tissues in contact with the external environment, located mainly in the skin, nose, lungs, stomach, and intestines, act as a link between bodily tissues and the innate and adaptive immune systems, and present antigens to T cells of the adaptive immune system. Granulocytes are leukocytes with granules in their cytoplasm. They reside in connective tissues and mucous membranes and regulate inflammatory response. They are most often associated with allergy and anaphylaxis. They secrete chemical mediators that are involved in defending against parasites and play a role in allergic reactions. Natural killer (NK) cells are lymphocytes of the innate immune system that do not directly attack invading microbes, but destroy compromised host cells, like tumor or virus-infected cells, recognizing them by low levels of a cell-surface marker MHC that can arise in viral infections of host cells. Normal body cells are not recognized and attacked by NK cells because they express intact self MHC antigens.
- Inflammation is one of the first responses of the immune system to infection, producing redness, swelling, heat, and pain, caused by increased blood flow into tissue when eicosanoids and cytokines are released by injured or infected cells. Eicosanoids produce fever and the dilation of blood vessels associated with inflammation and leukotrienes that attract certain white blood cells (leukocytes). Common cytokines include interleukins responsible for communication between white blood cells; chemokines that promote chemotaxis; and interferons that have antiviral effects, such as shutting down protein synthesis in the host cell. Growth factors and cytotoxic factors may also be released. These cytokines and other chemicals recruit immune cells to the site of infection and promote healing of damaged tissue following the removal of pathogens. The complement system is a biochemical cascade that attacks the surfaces of foreign cells. It contains over 20 different proteins and is named for its ability to "complement" the killing of pathogens by antibodies. Complement is the major component of the innate immune response. This recognition signal triggers a rapid killing response as a result of signal amplification after sequential proteolytic activation of complement molecules. After complement proteins initially bind to the microbe, they

activate their protease activity, which in turn activates other complement proteases, and so on producing a catalytic cascade that amplifies the initial signal by controlled positive feedback. The cascade results in the production of peptides that attract immune cells, increase vascular permeability, and coat the surface of a pathogen, marking it for destruction. This deposition of complement can also kill cells directly by disrupting their plasma membrane via the formation of a membrane attack complex.

Each of these innate response mechanisms is a complex control system that acts independently using transportation infrastructure and manufacturing mechanisms to destroy attacker cells and viruses, and most of them use those same transportation infrastructures to transmit chemical signals to other innate and adaptive immune system components as part of a coordinated response to attack.

- **Adaptive response** adds stronger immune response and immunological memory, where each pathogen is "remembered" by a signature antigen. Response is antigen-specific and requires recognition of specific "non-self" antigens. Specificity supports generation of responses tailored to pathogens or pathogen-infected cells. These tailored responses are maintained by "memory cells" used to quickly eliminate recurrences. Adaptive immune system cells are lymphocytes operating in the lymphatic system. B cells and T cells are derived from hematopoietic stem cells in bone marrow. B cells are for humoral (bone) response and T cells are for cell-mediated response. T cells recognize specific self-antigens by exposure in the thymus, while B cells receptors recognize native (unprocessed) antigen without any antigen processing. Such antigens are molecules found on surfaces of pathogens or haptens (e.g., penicillin) attached to carrier molecules. Each lineage of B cell expresses a different antibody, so the complete set of B cell antigen receptors represent all the antibodies that the body can manufacture. When B or T cells encounter related antigens they reproduce "clones" that target the same antigen. These antibodies circulate in blood plasma and lymph, bind to pathogens expressing the antigen and mark them for destruction. Antibodies can also neutralize challenges directly, by binding to bacterial toxins or by interfering with the receptors that viruses and bacteria use to infect cells. When B cells and T cells are activated and begin to replicate, some of their offspring become long-lived memory cells that remember each specific pathogen encountered and can mount a strong response if the pathogen is detected again.

This adaptive response system is a complex control system composed of many other complex control systems that act in concert using transportation infrastructure and manufacturing mechanisms to destroy attacker cells and viruses, and most of them use those same transportation infrastructures to transmit chemical signals to other adaptive immune system components as part of a coordinated response to attack.

An interesting analogy can be made to the systems of threat and attack in the information technology realm. This involves methods and mechanisms to deter, interdict, prevent, detect, respond, and adapt in the face of undesired threat actors and their mechanisms and methods of attack. They also involve other infrastructure elements and use informational transportation to actively update defenses, but with rare exception they do not involve manufacturing (other than by humans external to the operational systems) or internal adaptation.

Skeletal system

The Skeletal System:²⁰⁵ Maintains structural integrity and supports immune response, builds blood cells, and stores immune system memory cells. Vertebrates have Internal skeletons (endoskeletons) assembled from calcium and organic tissues typically composed of bones and cartilages.

- **Bones** are externally rigid organs that provide structural support for the body, assist in movement by opposing muscle contraction, and they form a protective wall around internal organs. Bone exteriors are primarily made of inorganic minerals, such as hydroxyapatite, while the remainder is made of an organic matrix and water. The hollow tubular structure of bones provide resistance against compression while staying lightweight. Most cells in bones are osteoblasts, osteoclasts, or osteocytes. Bone tissue is a dense connective mineralized tissue that gives rigidity with a honeycomb-like three-dimensional internal structure. They produce red and white blood cells and provide calcium and phosphate storage at the cellular level. Other types of tissue found in bones include bone marrow, endosteum and periosteum, nerves, blood vessels and cartilage. Cartilage between bones is used in vertebrates to resist stress at points of articulation in the skeleton and is usually encased in perichondrium tissue. Ligaments are elastic tissues that connect bones to other bones, and tendons are elastic tissues that connect muscles to bones.
- **Bone marrow**²⁰⁶ is a semi-solid tissue found in the spongy (cancellous) portions of bones. In birds and mammals, bone marrow is the primary site of new blood cell production (haematopoiesis). It is composed of hematopoietic cells, marrow adipose tissue, and supportive stromal cells. Human marrow produces about 500 billion blood cells per day that enter circulation via permeable vasculature sinusoids in the medullary cavity. All blood cells are created in bone marrow but lymphoid cells migrate to lymphoid organs (e.g. thymus) to complete maturation. At the cellular level, the main functional component of bone marrow is the progenitor cells that mature into blood and lymphoid cells. Marrow contains hematopoietic stem cells which produce the three classes of circulating blood cells: white blood cells (leukocytes), red blood cells (erythrocytes), and platelets (thrombocytes).
- **Stromal** cells support hematopoiesis by providing a specialized microenvironment that influences the function and differentiation of hematopoietic cells. For example, they produce colony-stimulating factors, which help regulate blood cell formation. This includes; Fibroblasts (reticular connective tissue), Macrophages (deliver iron for red cell hemoglobin synthesis, Adipocytes (fat cells), Osteoblasts (synthesize bone), Osteoclasts (resorb bone), and Endothelial cells, which form the sinusoids. These are derived from endothelial stem cells, which are also present in the bone marrow. Bone marrow is also a nest for migratory memory T cells and a sanctuary for plasma cells. Memory B and T cells live in the parenchyma in dedicated survival niches organized by stromal cells. This memory is maintained over time in the form of quiescent cells or by repeated antigenic restimulation. Bone marrow protects and optimizes immunological memory during dietary restriction. Bone marrow is core to immune activities of: hematopoiesis, osteogenesis, immune response, distinction between self and non-self

205 <https://en.wikipedia.org/wiki/Skeleton>

206 https://en.wikipedia.org/wiki/Bone_marrow

antigens, central immune regulatory function, storage of memory cells, immune surveillance of the central nervous system, adaptation to energy crises, and provision of mesenchymal stem cells for tissue repair.

- Bone marrow stroma contains mesenchymal stem cells (MSCs), multipotent stem cells that can differentiate into a variety of cell types. MSCs have been shown to differentiate, in vitro or in vivo, into osteoblasts, chondrocytes, myocytes, marrow adipocytes, and beta-pancreatic islets cells.
- The blood vessels of bone marrow constitute a barrier, inhibiting immature blood cells from leaving the marrow. Only mature blood cells contain the membrane proteins required to attach to and pass the blood vessel endothelium. Hematopoietic stem cells may also cross the bone marrow barrier, and may thus be harvested from blood.
- The red bone marrow is a key element of the lymphatic system as a primary lymphoid organ that generates lymphocytes from immature hematopoietic progenitor cells. The bone marrow and thymus are the primary lymphoid tissues involved in production and early selection of lymphocytes. Bone marrow also performs a valve-like function to prevent the backflow of lymphatic fluid in the lymphatic system.
- Biological compartmentalization is evident within bone marrow, in that certain cell types tend to aggregate in specific areas. For instance, erythrocytes, macrophages, and their precursors tend to gather around blood vessels, while granulocytes gather at the borders of the bone marrow.

The skeletal system is an infrastructure for manufacturing of components for the rest of the body as well as infrastructure supporting movement. Transportation within and outside of the skeletal system is used to bring in nutrients and immune system components, differentiate and store them in specific environments, control movement within and between the bones and the rest of the body, and many other functions.

Urinary system

The Urinary System:²⁰⁷ Land vertebrates produce ammonia as a by-product of digestion which is turned into urea, processed by kidneys²⁰⁸, mixed with water, and excreted as urine. In placental mammals, it consists of the kidneys, ureters, bladder, and the urethra. It: eliminates urine from the body; regulates blood volume, pressure, and pH; controls levels of electrolytes and metabolites; helps synthesize calcitriol (active form of Vitamin D); and stores waste before removal. The kidneys have an extensive blood supply via the renal arteries which exit the kidneys via the renal vein. They have nephrons that filter blood into and through converging tubules (collecting ducts), that join to form the minor then major calyces, that join the renal pelvis, followed by the ureters, which transport urine into the urinary bladder and through the urethra and penis or vulva to urination.

The urinary system is covered in a unique lining called urothelium, a type of epithelium that can flatten and distend. It is regulated by hormones of the endocrine system and influenced

207 https://en.wikipedia.org/wiki/Urinary_system

208 [https://en.wikipedia.org/wiki/Kidney_\(vertebrates\)](https://en.wikipedia.org/wiki/Kidney_(vertebrates))

by the circulatory and nervous systems. Aldosterone acts on the distal tubules and collecting ducts of the nephron to increase reabsorption of sodium from the filtrate, producing retention of water, which increases blood pressure and blood volume. Vasopressin regulates the retention of water by increasing water reabsorption in the collecting ducts by increasing water permeability by inducing changes in water channels within plasma membranes. Urine is ejected through the urethra under voluntary control. Micturition involves coordination between the central, autonomic, and somatic nervous systems. Brain centers that regulate urination include the pontine micturition center, periaqueductal gray, and the cerebral cortex.

These complex control systems involve multiple body systems, act locally and in collaboration through higher level control systems invoked by fluid transported by blood, electrical signals through nerves, and lymph, and manufacturing urine and cleaned blood from blood.

Integumentary system

The Integumentary System:²⁰⁹ Consists of the skin and structures or growths that cover it (feathers, scales, hair of mammals, etc.), claws, nails, hooves, and so forth. It protects animals from environmental hazards including excess solar radiation (by excreting melanin), predators and external organisms (including infections), supports temperature regulation (insolation and sweating), prevents dehydration, maintains homeostasis, excretes waste material (sweating), senses touch, pressure, pain, heat, and cold, and produces vitamin D and other biochemicals, stores water, fat, glucose, and vitamin D, maintains body form, generates new cells to repair minor injuries, and distinguishes, separates, and protects the organism from its surroundings.

It is a set of organs that acts as a protective physical barrier between the external and internal environment. It also maintains water balance, protects deeper tissues, excretes waste, regulates body temperature, and contains sensory receptors that detect pain, sensation, pressure, and temperature. The skin (integument) is a composite organ, made up of at least two major layers of tissue: the outermost epidermis and the inner dermis, separated by a basement membrane (basal lamina and reticular lamina). The epidermis comprises five (or 6) layers: the strata corneum, (where skin is thicker lucidium), granulosum, spinosum and basale. The dermis comprises papillary and reticular layers, containing connective tissues, blood vessels, glands, follicles, hair roots, sensory nerve endings, and muscular tissue. Between the integument and deep body musculature there is a transitional subcutaneous zone, the hypodermis. Skin is one of the largest organs of the body, and is the body's first line of defense against infection, temperature change, and other challenges to homeostasis.

- The **epidermis** is the strong, superficial layer and the first line of defense against the external environment. The epidermis is regenerated from stem cells found in the basal layer that develop into the corneum, has no blood supply, and gets nutrition from the underlying dermis. Its main functions are protection, absorption of nutrients, and homeostasis. In structure, it consists of a keratinized stratified squamous epithelium; four types of cells: keratinocytes, melanocytes, Merkel cells, and Langerhans cells. Keratinocyte produces keratin, a fibrous protein that aids in skin protection, and forms the epidermal water barrier by making and secreting lipids. Skin is keratinized, except for lining of mucous membranes, like the inside of the mouth where non-keratinized

209 https://en.wikipedia.org/wiki/Integumentary_system

cells allow water to "stay" on the structure. Keratin stiffens epidermal tissue to form nails that grow from a thin area (the nail matrix) at an average of 1 mm per week, with the lunula as the crescent-shape area at the base of the nail that mixes with matrix cells. In non-primates the keratinizing system at the terminus of each digit produces claws or hooves. The epidermis of vertebrates is surrounded by two kinds of coverings produced by the epidermis. In terrestrial vertebrates, it's the stratum corneum (dead keratinized cells). The epidermis is glandular in all vertebrates. Multicellular epidermal glands penetrate the dermis, where they are surrounded by blood capillaries that provide nutrients and for endocrine glands transport their products.

- The **dermis** is underlying connective tissue layer that supports the epidermis. It is composed of dense irregular connective tissue and areolar connective tissue such as a collagen with elastin arranged in a diffusely bundled and woven pattern. The dermis has two layers: the papillary and reticular layer. The papillary layer is the superficial layer that forms finger-like projections into the epidermis and consists of highly vascularized, loose connective tissue. The reticular layer is the deep layer of the dermis with dense irregular connective tissue. These layers give elasticity to the integument, making it stretchable and flexible while resisting distortions, wrinkling, and sagging. The dermal layer terminates blood vessels and nerves and holds chromatophores and the bases of hair, feathers, and glands.
- The **hypodermis** (the subcutaneous layer), invaginates into and is attached to the dermis by collagen and elastin fibers. It is composed of adipocyte cells specialized in accumulating and storing fats that are grouped together in lobules separated by connective tissue. The hypodermis is also an energy reserve where fats contained in the adipocytes are put back into circulation via a venous route during intense effort or when other energy-providing substance is unavailable. The hypodermis participates in thermoregulation since fat is a heat insulator and sweat is a cooling mechanism.

It seems clear to me after going through all of this evolution of biological systems, that they are the most complex and impressive control systems I have ever seen, and they make human produced cybernetic systems look pathetic by comparison. The extent to which they are intertwined across multiple interdependent feedback systems, and the extent to which people seem to have figured out what they do and how they do it, are both truly impressive. And yet, we clearly do not know how it all works at full depth.

In fact, humans don't really know in full detail how a cell works, but we seem to be getting much closer to it. We seem to understand a lot about the structures and feedback systems including chemical processes and larger systems and how they interact. But the area we seem to be truly ignorant of today is how the brain really works. We know lots of details about the trees in the forest, and we know at some high level how the forest works, but something still evades us in the cognitive realm.

In terms of infrastructure, manufacturing, and transportation, we know a great deal about how it works within the body, but it seems befuddling that the differences between everything described here for all vertebrates and modern humans appears to be vanishingly little. And in terms of timelines, the amount of time that has passed since the simplest forms of life and today and the changes identified in different species that have arisen are both stunning and seemingly endlessly slow.

Evolutionary timelines

In the life evolutionary timeline on Earth²¹⁰, periods of great variation and reproduction are punctuated by mass die-offs, usually associated with catastrophic global events that selective species survive, with dying species leaving open niches. The surviving species diversify and evolve until the next event, and so forth.

The resulting process seem similar to annealing processes for metals where heat is added, metal is struck repeatedly, and cooling applied rapidly. The net effect is that molecular alignment is changed to harden and strengthen the metal.

Surviving species have gone through many cycles to the point where the survivors have adapted to a wide range of conditions and some seem more likely to survive the next major change.

In terms of transportation, infrastructure, and manufacturing, internal systems have made many advances over the course of time. But until very recently, little progress has been made in the external artifacts and their use for these same purposes. Except for limited tool use and carrying or dragging by individuals, nothing of substance happened between the beginning of life and the emergence of hominids only a few million years ago. And real progress found in the fossil records emerged only in the last 100,000 years. If a generation is perhaps 25 years, that's only 4,000 generations worth of evolution, less than the number of generations of dogs bred by people over the last 10,000 years.

But then, something happened

The discussion stops here, not because transportation, manufacturing, and infrastructures stopped, but because something happened in the last 100,000 years that dramatically changed the rates of travel, scale of manufacturing, and expanse of external infrastructure. That was the appearance of hominids and their co-evolution with...

210 https://en.wikipedia.org/wiki/Timeline_of_human_evolution