Does Your Brain Need You?
An Introduction to Neuroscience and Consciousness

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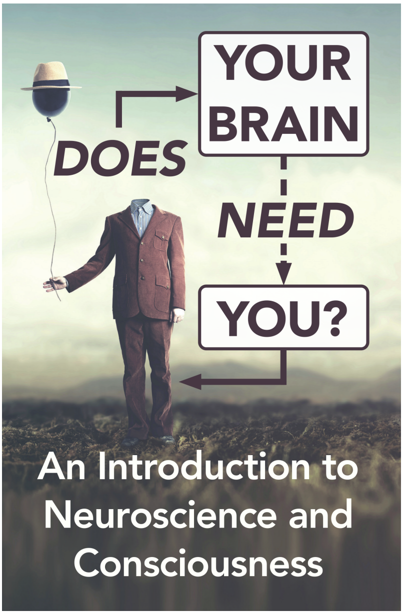

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PHILOSOPHY
POPULAR SCIENCE
PSYCHOLOGY
NEUROSCIENCE

Dedication

I drew my motivation to write this book from something the neuroscientist Michael Graziano said:

> “You go to a conference on consciousness, and in some ways, I feel like I’m at a conference on Tolkien’s Middle Earth. And everyone is talking about Middle Earth. Are Orcs really Elves that got modified and this and that and you can talk and talk about it and what it is really magic in Middle Earth and then I’m the iconoclast who is foolish enough to say yeah, that’s true, but that’s all a description of something and it exists only in simulation. It exists only as information, only as a description. There actually isn’t a real Middle Earth. Well, you could say it’s a description of a real thing because it’s a kind of warped description of Medieval Europe, but it doesn’t exist physically as such, and this is very much what I would say about awareness. —*Michael Graziano, Closer to Truth*, 2015

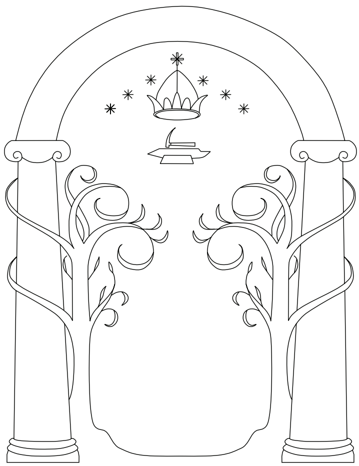

Figure 1: “The Doors of Durin, Lord of Moria. Speak ‘friend’ and Enter!” —*Lord of the Rings*

Introduction

In this book, I will examine, from the ground up, questions about consciousness. Many steps toward the understanding of the self will tell you nothing about the self—until your right hemisphere connects everything into one idea as you understand the concept. Such an insight is also called an *epiphany*. Using a brain scanner, we can actually observe someone having an epiphany when the brain's right hemisphere suddenly buzzes with activity. While the left hemisphere deals with concrete entities, the right hemisphere helps with looking for alternative meanings. For example, the left hemisphere might identify a "bank" as a financial institution, while the right hemisphere also considers it to be the edge of a river ("river bank").

In the Old Indo-Aryan language Sanskrit, an *epiphany* leading you to the answer about who you are is called "bodhi," which literally means "awakening" or "enlightenment." Similarly, the name "Buddha" means the "Awakened One" or the "Enlightened One." A similar idea can be found in Zen Buddhism as *Satori* (Japanese 悟り) which corresponds to a very *sudden* insight.

This book shows some of the steps leading to Satori, combining the insights of philosophers and scientists into a new idea of what the "self" means. With this knowledge, we can better reflect on our own values and *act* according to reality rather than just blindly following someone else's beliefs.

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Publisher's Note

Writing and editing this book of the series turned out to be a major challenge. Not only did it lead me to change my views on free will and consciousness, but I also discovered it will take more time to put my thoughts into words. The actual process of creating this book has been very rewarding. With the help of the book template (as discussed in *Better Books with LaTeX the Agile Way*), I was able to speed up the writing process and am very pleased about the result. What helped me also was reaching into the community by starting a small local Meetup group and receiving a lot of feedback.

Thank you for keeping up the tradition of reading books. You and your fellow readers have created a market for this book. I hope that I can meet your expectations and I am looking forward to feedback, no matter whether it is positive or negative. To send general feedback, mention the book title in the subject of your message and simply send it to feedback@lode.de. You can also contact us at https://www.lode.de/contact if you are having a problem with any aspect of the book, and we will do our best to address it. Also, we cordially invite you to join our network at https://www.lode.de.

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Preface

> We are not always what we seem, and hardly ever what we dream.
>
> —Peter S. Beagle, *The Last Unicorn*

This book came about when working on my book series *Philosophy for Heroes*, which asks the question how can we be leaders without following the standard tropes of self-sacrifice? When exploring this question, it soon dawned on me that it takes many more than a few pages to delve into the topic. The reader would have to understand philosophy, language, biology, physics, neuroscience, and consciousness in order to effectively reflect on his or her own life. And self-reflection is necessary to be a leader: you do not want to be following a fantasy, but instead to lead people forward.

As the topics of neuroscience and consciousness are more current than ever, I decided to summarize the book series to create this comprehensive standalone book.

My goal with the book is to give you an introduction to neuroscience that is not separated into different parts. I hope to focus on helping you to answer the questions: What is the self? Does your brain even need a "self"? What is this seemingly mysterious subjective experience of ourselves that we share? How can we think, dream, plan, feel, and make decisions?

This book approaches consciousness from the scientific point of view, explaining not only what it is, but also the evolutionary steps leading up to it. I welcome you to read the studies I have cited and pay tribute to the many scientists and philosophers who paved the way to make this book possible.

Clemens Lode
Düsseldorf, Germany, December 1st, 2020

Chapter 1

The Brain

> “Our imagination is stretched to the utmost, not, as in fiction, to imagine things which are not really there, but just to comprehend those things which are there.

—Richard P. Feynman, *Character of Physical Law*

When we look at a picture or a scene, we take for granted that what we are seeing is the entire picture, that we have an objective view, and that what we see is real. However, we are not cameras. We *think* we have looked at the whole picture or scene, but, in reality, we likely have perceived only a filtered version of it, and all we might remember are several details that caught our attention. To explore this curious difference between our experience and reality, the first step is to understand the brain's architecture. Given that consciousness must sit somewhere between perception and action, we will examine the entire stream of data, from sense data to action.

History of Evolutionary Thought. To understand the stream of consciousness, we first need to understand the theory of evolution. For this, we will look at the individual advances philosophers and scientists made over millennia to finally arrive at Darwin's theory of evolution.

Basics of Evolution. Next, understanding the principles of evolution helps us to understand what kind of designs nature can produce, and what conditions need to be met for a system to evolve.

The Evolution of Attention. Before we can discuss the brain's higher functions, we first have to understand all its parts. The best approach is to look at its evolution from the first multi-cellular lifeforms and work our way up to the brain of modern mammals.

The Rise of the Primates. To comprehend the most modern part of our brain, the neocortex, we have to go into depth and compare our brain to that of our closest cousins, the apes. Then, to gain insight into how our brain evolved, we also need to take a look at the environments in which our human ancestors spent most of their evolutionary history.

A Glimpse into the Brain. To learn about our subjective experience of the world, we need to look at how sense data arrive in and are processed by our brain. For this, we examine the visual system from the eyes to the visual cortex.

Creating a Body Schema. To understand how our brain initiates actions, we need to know how the brain gains a sense of our body. We build a body schema to be able to differentiate between ourselves and our environment.

Theory of Mind. Finally, we need to explain how the brain makes sense of itself. Consciousness goes beyond seeing oneself in the mirror; it also involves knowing what we (and other people) are thinking about.

1.1 History of Evolutionary Thought

> “It makes one wonder what the evolutionary tree of this idea [the theory of evolution] would look like, were it an organism that could be mapped out by fossil record rather than words. The concept is one that faded nearly into obscurity, only now to be revived with slight mutation. What I personally gather from this is that survival of ideas depends less on the actual quality of the idea, but rather the climate into which it is introduced. Quite literally, survival of the fittest, but not necessarily the best.
>
> —*Aquinas and Evolution*

Evolution itself still evolves by adding more abstraction layers to it (for example, DNA, multicellularity, sexual reproduction), by creating conditions for faster evolutionary processes within an organism

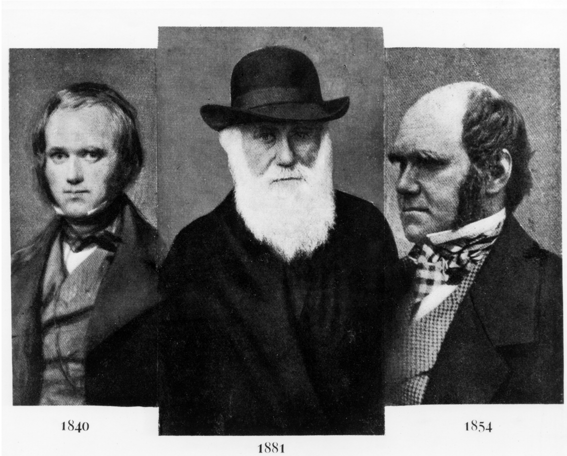

Figure 1.1: Three photographs of Charles Darwin, father of the *Theory of Evolution*, at three different times of his life (image source: Shutterstock).

(immune systems, the mind), and finally by having such an organism recreate new artificial organisms based on these principles (artificial life). Each of those *evolutions of evolution* leads to more complex organisms on Earth.

Significant steps along this path include:

- **3.8 billion years ago**: Earth cools down, meteoroid bombardment ends, first protocells with RNA appear, deep sea hydrothermal vents provide basic metabolism for protocells.
- **2.45 billion years ago**: Cells produce oxygen toxic to most other existing bacteria, massive climate shift, photosynthesis begins (Great Oxidation Event).
- **2 billion years ago**: Specialized cells appear, genotype / phenotype differentiation begins, cell machinery separates into DNA, RNA, lipids, and proteins.

- **1.5 billion years ago**: Multicellular organisms appear.
- **1.2 billion years ago**: Sexual reproduction and crossing over of DNA speed up evolution.
- **500 million years ago**: Adaptive immune systems based on an evolutionary algorithm appear, first animals appear.
- **220 million years ago**: Mammals appear.
- **100 million years ago**: Primates appear.
- **65 million years ago**: Asteroid collides with Earth (Cretaceous–Paleogene extinction event), climate shifts, dinosaurs become mostly extinct, rise of the mammals begins.
- **8 million years ago**: Last common ancestor of humans, chimpanzees, and gorillas disappears.
- **2.5 million years ago**: Humans appear.
- **300,000 years ago**: Modern humans with a "Darwin machine"[1] (a high-speed evolutionary algorithm) in the brain appear.
- **70,000 years ago**: Writing is invented.
- **2,000 years ago**: First mechanical computer for astronomy (Antikythera mechanism) is developed.
- **1,000 years ago**: Scientific method is developed.
- **1543**: Scientific Revolution begins.
- **1859**: Theory of evolution is published.
- **about 100 years ago**: Theory of relativity and quantum theory are published.
- **1950s**: Theory of DNA is published, digital computer is developed, cellular automata, and evolutionary algorithms are used for the first time on the computer.
- **1960s**: First human lands on the Moon, development of the Internet starts.

[1] Calvin, 1987.

- **1970s**: Theory of adaptive immune systems and theory of memes are published.
- **1980s**: Theory of neural Darwinism is published.
- **1990s**: Artificial life is created on the computer, World Wide Web is launched.

Coming back from this bird's eye perspective to the ground, when people think about the theory of evolution, it is typically Charles Darwin who comes to mind—he is celebrated as the one who came up with a *revolutionary* idea. But people tend to remember only the first (or last) participants in a long series of events. For example, take the first humans on the moon: Neil Armstrong and Buzz Aldrin are well known, but who remembers the person staying in orbit, Michael Collins?

Michael Collins was the third person on the Apollo 11 mission, remaining in orbit while Armstrong and Aldrin descended onto the moon. The mission would have been impossible without him, just as the mission would have been impossible without the people building the moon lander, the computers, and the rocket, or the people managing the operation on the ground. "Heroes" would not have been able to land on the moon and successfully return. The operation was too complex to be achieved with a singular heroic effort; thousands of things had to be just right. Sure, the astronauts were risking their lives, but so did the people on the ground, every day they drove to work.

Collins feared that something would happen and that he would be the only one to return, with all the spotlight on him, then being "a marked man." In a recent interview, at the age 78, he said that he is bothered by today's inflation of heroism and adulation of celebrities, adding that he is no hero and that "heroes abound, but don't count astronauts among them. We worked very hard, we did our jobs to near perfection, but that is what we had been hired to do."

Learning about the complexity of the moon landing relativizes the role of the astronauts, just like learning about the centuries-long evolution of the theory that Darwin made famous relativizes his role. Neither the moon landing nor the theory of evolution is the result of magic or a singular heroic effort. Each can be understood by looking at the whole chain of industry, of scientists, and of ideas.

We are often taught only about the last element of a long chain of events. And those not familiar with a subject see this last element as almost supernatural. In science, it is easy to overlook how theories were developed over centuries. This applies to the theory of evolution, which is difficult to understand if one simply jumps over thousands of years of scientific progress and focuses only on the final result.

In ancient times, during Homer's era (ca. 750 BC), life was understood as the result of the action of whimsical, inconsistent gods. In this world, the rather primitive statement by Thales (626–548BC), "The first principle and basic nature of all things is water," launched a dramatic shift in people's minds. No longer were people discussing the moods and personalities of human-like gods. Instead, these early philosophers looked for patterns in nature to explain natural events. Rather than relying on stories and myths, people were beginning to test truths on a first-hand basis.

One of the first documented thinkers who promoted this idea—that the phenomena of nature cannot be explained by supernatural gods or magic, but by observable facts—was Anaximander (610–547 BC). Starting with Thales' idea that water is the origin of all things, and the observation of humidification and cloud formation, Anaximander concluded that in earlier times, the Earth must have been covered by water. The existence of fossils further strengthened his view, which led to the conclusion that humans also had to have emerged from water.

Not long after, Empedocles (490–430 BC) offered an explanation of why organisms in nature look as if someone had designed them for a specific purpose. Those organisms happened to have properties that allowed them to survive in their environment. Those that did not died and hence, were not part of nature anymore. He also held the view that life could have developed without an underlying purpose or a godly creator.

Further support of this idea was provided by Aristotle (384–322 BC). Like Charles Darwin 2,000 years later, he was an explorer of nature, analyzing and classifying more than 500 different animal species. He recognized that animals' properties were specifically adapted to their environment. He disagreed with Empedocles, though, as to whether or not they had a higher purpose.

Later, in the Roman empire, Lucretius (97–55 BC) took interest in the subject and based his work *De Rerum Natura*[2] on the writings of Epicurus. The book describes the universe as a purely mechanistic entity, without supernatural influence. This idea thrived within an environment of the then-popular Stoicism, the view that to attain happiness, you need to understand nature. Contrary to the theory of evolution, though, people still believed that everything happened for a reason, that the world was designed for a purpose (teleology).

With the deterioration of the Roman Empire came the attempt to keep the empire together by raising Christianity to the state religion. Augustin of Hippo (354–430)—one of the so-called "Church Fathers" with a strong influence on the philosophy and theology of Christianity—argued against the idea of literal interpretation of the Bible, claiming that new species can develop.

The Roman Empire fell in 476, and it took until the 9th century for learning centers in the Middle East to be rediscovered and to trans-

[2] "On the Nature of Things," published by Cicero [106–43 BC] after Lucretius' death.

late old Greek and Latin books. Similarly to Aristoteles, Al-Biruni (776–868) categorized in his *Book of Animals* over 350 different animal species, their environments, and their places on the food chain. One of his notable discoveries was that animals are constantly in a fight for survival, and that successful properties of the animals are inherited to the next generation, resulting in adaptations and even new species.

The zenith of Arabic scholarship was with Nasīr al-Dīn Tūsī, a Persian polymath (1201–1274). He stated that "The organisms that can gain the new features faster are more variable. As a result, they gain advantages over other creatures. [...] The bodies are changing as a result of the internal and external interactions." He even theorized that humans are but a middle step of an evolutionary stairway, with animals as the precursors, and humans with spiritual perfection as the successors.

As climatic conditions in Europe improved during the High Middle Ages, scientific progress returned. From the Middle East, translations from Arabic books, old Greek and Latin writings, and even scientists returned to Europe, creating the foundation for people like Thomas Aquinas (1225–1274). His view was that God provided an objective world with cause and event in an endless loop, and that animals had a god-created potential to develop into new species. Besides the initial potential of nature to create this diversity, there would be no further godly interventions in this progress.

The Crusades and the Mongol Invasion in the Middle East, and the subsequent destruction of libraries and the fabric of society, left Europe as the keeper of knowledge. With the beginning of the Little Ice Age (1300–1750), a strengthening of the Catholic Church, the persecution of heresy by religious inquisition, as well as with a lack of literacy in the general population, it took until René Descartes (1596–1650) for a revival of a mechanical view of the universe.

Benoît de Maillet (1656–1738) was a student of geology. Starting from a theory by Descartes, namely that the Earth had originally been entirely covered by water, and by studying fossilized shells embedded in sedimentary rocks on mountains high above seal level, he concluded that the Earth must have been created not by a singular act, but by a slow, natural process. He estimated the true age of the Earth at around 2 billion years and assumed that humans must have been developed from animals that came out of the water.

Finally, in the following two centuries, the idea of evolution took off.

- First, while fossils were found and considered the remains of life forms from ancient times, the fossil record was very sparse. This gap began to close thanks to industrialization, which increased the need for professional geologists, and coal mining uncovered new fossils.
- Second, the comparison of specimens from different geographical areas provided evidence for a relationship between the species: the greater the distance between two species, the more they differed from each other.
- Third, the ancient writings became known and available to more and more people. Book printing grew from a few hundred titles per year in the 17th century to thousands of titles per year in the 18th century.
- Fourth, the general science of categorizing the natural world created the foundation for further scientific theories including the theory of evolution by filling gaps, focusing the research on the questions that remained open.

> **Theory of Evolution** · The *theory of evolution* states that the process of evolution tends to create systems in each new generation that are better adapted to the environment than the parent generation.

With this background in mind, Charles Darwin's (1809–1882) *Theory of Evolution* in his book *Origin of Species* looks like a much smaller step than when taken on its own. It did not come out of the void and we have to remember those who paved the way. Charles Darwin's research certainly was a heroic act, given the resistance he faced (and his work still faces). His integration of all the pieces that were available to him, including his own research that he conducted when taking part in the voyages of the HMS Beagle around the world, was revolutionary—despite having an *evolutionary* record.

Likewise, the history of the theory of evolution did not end with Darwin. There were (and still are) many gaps being filled. Advances in other fields of technology opened the door for genetic research and we are only now slowly beginning to understand the code in which life is written.

> Science is a collaborative enterprise spanning the generations. We remember those who prepared the way, seeing for them also.
>
> —Carl Sagan, *Cosmos: Blues for a Red Planet*

1.2 Basics of Evolution

> Still, it needs to be said that the light of evolution is just that —a means of seeing better. It is not a description of all things human, nor is it a clear prediction of what will happen next.
>
> —Melvin Konner, *The Tangled Wing*

The purpose of the theory of evolution is to explain the wide array of life forms on Earth. Knowledge about the origin of species allows us to better understand why a particular organism has certain properties. While this is often obvious by looking at the environment of an organism, for example by looking at the teeth and the food, or the leaves and the precipitation and angle of sun rays, more complex behavior seems baffling, especially that of humans. Why and how did humans develop? Why do we have such a big brain? What is the reason for our behavior? All these subjects can be better understood when we understand our past—how life, and humans in particular, developed on Earth.

> He who does not understand the uniqueness of individuals is unable to understand the working of natural selection.
>
> —Ernst Mayr, *The Growth of Biological Thought*

1.2.1 Selection of Systems

Before we discuss evolution in detail, it is important to note that parts of the evolutionary process can be applied not just to living organisms, but also to *any* system—for example to chemical systems, simulated life forms in a computer simulation, or thought patterns in the brain. One of these parts is the selection process. To understand selection, it is important to establish a few definitions first:

Entity · An *entity* is a "thing" with properties (an identity). For example, a plant produces oxygen, a stone has a hard surface, etc.).

Identity · An *identity* is the sum total of all properties of an entity (e.g., weight: 160 pounds, length: 6 feet, has a consciousness, etc.).

PROPERTY · A *property* refers to the manner in which an entity (or a process) affects other entities (or other processes) in a certain situation (e.g., mass, position, length, name, velocity, etc.).

CONFIGURATION OF A PROPERTY · The *configuration of a property* relates to the intensity of a certain property of an entity.

EFFECT · An *effect* is the change caused to the configuration of the properties of an entity (e.g., the heating of water changes its temperature).

AGGREGATE · An *aggregate* is a number of entities that have a reciprocal effect on one another, so that they can be considered collectively as their own entity (e.g., a cup full of water—all water molecules interact with each other).

STRUCTURE · A *structure* is a description of required properties, dependencies, and arrangement of a number of entities (e.g., cube-shaped).

SYSTEM · A *system* is an aggregate with a definite structure (e.g., an ice cube is a system of frozen water molecules).

PROCESS · A *process* describes the mechanism of a cause working to an effect (e.g., if you put an ice cube into a glass of water, the cooling of the water is the process).

TIME · *Time* is a measurement tool to put the speed of processes in relation to each other.

PROCREATION · *Procreation* is a process by which a system creates (on its own or with the help of the environment) a new entity with a similar or (preferably) the same structure as itself.

GENERATION · A *generation* is a set of systems during one cycle of procreation.

GENOTYPE · The *genotype* is a system that is the blueprint for the phenotype.

PHENOTYPE · The *phenotype* is the actual body of a life form. Changes in the phenotype generally do not have effects on the genotype. Generally only the phenotype interacts directly with the environment.

MUTATION · A *mutation* is a change of the genotype of a life form. This change can, but does not necessarily, have consequences for the phenotype.

1.2.2 Mutations

Mutations, as our common knowledge suggests, are generally bad. No matter their effect for the overall population, for the individual life form, mutations are unwanted accidents. They happen, but they are not intended. An individual life form which is adapted to its environment does not want change. If the parent generation already has well adapted genes, the last thing they want is their offspring to have random changes.

Sometimes, multiple repair and protection mechanisms are bypassed by a mutation while it also is mutated in a way that it does not stop reproducing: that is cancer. To understand cancer, you have to understand multicellular organisms. For a single-celled life form, there is no such thing as cancer. Cancer is simply an unlimited self-replication of a cell. While this is exactly what you want for a single-celled life form, it possibly destroys the structure within a multicellular organism. If all of our cells divided uncontrollably, we would not survive. Our life depends on a highly organized and controlled process of cellular growth and death. Cancer for us occurs when those processes fail for a single cell. For example, when making a copy of themselves, most of our cells lose a few genetic base pairs at their ends (telomeres). Once they have lost a certain amount of code, they stop duplicating themselves. Any damage of a defective cell would then be limited by its remaining duplication cycles. Any form of cancer cells would need to have undergone a mutation that fixes the ends of its genetic code after each duplication.[3] In a similar fashion, there are other protection mechanisms in the cell that a cancer cell has to overcome. For example, scientists have found that there is a single gene regulating multi-cellularity in organisms. It acts like a brake to stop multiplication at the right times. If that gene is defective in a cell, it might end up multiplying indefinitely and cause cancer.[4]

1.2.3 Selection

> **FITNESS LANDSCAPE** · The *fitness landscape* is the sum of all environmental influences on an entity. For example, if you are sifting sand, a riddle screen lets small particles of sand fall through while larger stones are retained. In this case, the riddle screen and the shaking of the riddle screen would be the "fitness landscape." In nature, the fitness landscape would simply be the environment over time, including all other life forms, the climate, etc.

> **SELECTION (EVOLUTION)** · *Selection* is a process where some (or all) of a set of systems of similar structure are retained while the rest are discarded or destroyed. Which ones are retained and which ones are discarded depends on the relationship between the structure of the individual systems and the fitness landscape. In the example of the riddle screen, the screen lets small sand fall through while it "selects" larger stones.

Selection is a central element of evolution. It connects systems with environmental factors. When the environment changes, different systems are selected. In order for selection to work—or to make any difference or sense—there needs to be variation. As such, the mutation rate of a population is caught between two conflicting forces:

[3] Shay and Wright, 2011.
[4] Hanschen et al., 2016.

the tendency to replicate what works and fix any copying errors, and the need for some variety in the population in order for a population to evolve.

Nature's solution for the conflict between variety and preventing errors was to keep mutations as low as possible, while using sexual recombination at the same time. Like mutations, sexual recombination keeps up the variety within a population. But it also kept individual genes intact, reducing the probability for destructive changes: it simply recombined working copies, resulting in a varied, but very likely functioning organism. It is hard to compare it to any everyday concept because it is a very unique solution. The closest analogy might be editing a movie where you cut and rearrange parts instead of trying to change individual pixels.

As an example, imagine trying to sift identical stones with a fine riddle screen: nothing goes through. Or imagine trying to sift sand with a riddle screen: everything goes through. Likewise in nature, without change in the population, a population cannot move in any direction. If you use a finer riddle screen, more sand is retained. This changes the ratios between the different types of systems in the environment (for example the ratio between large stones and fine sand). Such changes could be caused by either selecting more (and discarding fewer), selecting fewer (and discarding more), or by selecting other (and discarding other) systems.

Another example would be imagining stones in a stream. The stones with the highest flow resistance experience the highest degree of erosion. They are "discarded" while rounder stones with lower flow resistance remain the same. Obviously, the "discarded" stones are not actually discarded but transformed into stones with lower flow resistance simply because erosion slowly removes the edges of those stones until they, too, become round.

The significant point is that selection applies to all things in the universe. It is simply a process describing the change of systems over time due to external influences by other entities. A system with lower "durability" will by definition not endure as long as a system with higher "durability," so after a while, you will see the ratio of systems with higher durability increase. For this principle, we do not even have to look much at nature, as it is very much a logical process based on the properties of the involved entities.

But for evolution to happen, another component is necessary. The system needs to be able to "clone" itself and replace the systems that were discarded during the selection process. Looking again at our example with the stones in the stream, you can imagine that over time, the stones get smaller and smaller until only sand remains that gets easily pushed down the stream. With no new stones being added to the stream, all stones eventually will have turned into sand and washed away—even the ones that were least resistant to the flow. To clarify, sand and stones in a riddle screen do not "procreate" in any form, so while they undergo a process of selection, they do not undergo a process of *evolution*. You could argue that the stones in a stream adapt to their environment by replacing themselves with a rounder version, but this is a borderline case as erosion is very much a one-way street.

1.2.4 Selfish Genes

As stated previously, for evolution to work, selection needs to be—as the term suggests—selective. This means that selection needs to be based on an individual life form's properties and not on a whole population of life forms. It is not enough that a change improves the ability for a life form to survive. It needs to improve the life form's likelihood of survival *relative to other life forms*. For example, if a life form has a mutation that produces chemicals that speed up the process of procreation but distributes these chemicals among all other life forms, every life form nearby profits, no matter whether they had the beneficial mutation or not. This is similar to the situation in an economy. Money, status, or reputation is given preferably to those people and companies that have methods more adapted to the environment (the market). A well-run restaurant with better service will attract more customers than a poorly run restaurant. If, at the end of the day, the better restaurant had to share its earnings with all other restaurants, it might have a harder time "evolving" and expanding its business.

With that, we arrive at a basic definition of evolution:

> **Evolution** · *Evolution* is the combination of the process of selection together with a system of cloning or procreation.

An exception to the rule of having to work for one's advantage are beehives. They consist of infertile worker bees and a single fertile queen. In this case, in terms of evolution, they can be seen as one large organism where individual worker bees have no problem sacrificing themselves for the greater good of the hive—if its queen survives, the worker bee's genetic material survives. This idea is best explained in Richard Dawkins' *The Selfish Gene* where he stresses how organisms tend to act primarily in favor of the survival of their genes, not necessarily of their own bodies.

1.2.5 Randomness

There are many slopes leading up a mountain, but there are but a few mountain tops.

From the outside, we see a population of individual organisms, with mutations causing diversity within the population. Over generations, the gene pool of the population slowly moves in a direction in which the organisms are better adapted to their environment. From this perspective, the driving force clearly is the environment. For example, let us say that within a population, there is one individual with a resistance to a certain disease. Over generations, his descendants will be more successful than other members of the population, so the gene with the resistance slowly spreads within the population until the majority has it. From there, another mutation might occur and spread in the same manner. Looking back, it seems that a single line of ancestors did all the "work" to find the advantageous mutation.

Evolution can be *very* predictable. For example, in nature, the problem of how to design a body or wings with low air resistance is solved again and again similarly because the underlying physics are always the same. There might even be only one (or very few) possible optimal solutions or paths to a problem so that you can even see identical genes in non-related species. As an example, imagine you have a mailing list with 10,000 addresses. You create two groups, sending half of them a message that you have a special ability to predict next week's stock market and that a certain share will go up. Likewise, you send the other half a similar message, but tell them the share will go down. After a week, the stock will go up or down and either way, you discard half your list. To the remaining 5,000—the people whom you told correctly whether the share would go up or down—you will send another message, reminding them about your correct prediction. And you divide them again in two groups, telling one that a certain share will go up, and the other that it will go down. After a few iterations, the remaining group of maybe 100 to 500 people will think you are some kind of genius always making the right prediction. Similarly, when looking only at the results in nature, we might think that some kind of a genius has designed life on Earth. But it only looks this way because we ignore the number of times nature has produced results that did not survive to procreate.

Another factor in the preference for believing in mutations as opposed to adaption to the environment is that it leaves the door open for random events. But even if it is agreed that the environment is the driving factor of evolution, someone could argue that changes in the *environment* are random. But if (supposedly) “random” events were frequent enough, we always have found a pattern in the form of a natural law. In terms of evolution, one could argue that, yes, “random” events drive evolution through mutation, but these events are not frequent enough (yet) to be discovered by science and made into a natural law. Likewise, a changing climate because of a volcanic eruption is a “random event”—but only “random” insofar as we do not have the necessary data and do not yet understand the processes that led to such an eruption.

1.2.6 Evolution as Waves

Imagine sending 100 rats into a maze and then wondering if the one that finds the way out is some kind of maze-genius. But now (after all rats have left the maze) fill it up with water, and then cause some waves at the entrance of the maze until the waves have traversed through the whole maze to the exit. Would you think that those water waves are some kind of intelligent water molecules that found the right way through the maze? Obviously not, water waves simply expand into all directions and create the illusion that they are somehow intelligent. Likewise, populations in nature should be looked at as waves, with different members of the population being at different positions of the wave. Through their genetic diversity, they also expand like a wave, checking every direction for the “exit”—a genetic code that is better adapted to their environment.

This can be seen for example in a study made with E. Coli bacteria.[5] The bacteria were spread on the left and right side of a large,

[5] See https://hms.harvard.edu/news/bugs-screen.

rectangle shape petri dish. The petri dish was divided into different sections with no antibiotics, some antibiotics, and toward the middle 10x, 100x, and 1000x the amount of antibiotics. Over the course of 11 days, the bacteria evolved to gain more and more resistance until they hit the center. Mutated bacteria with significantly higher antibiotic resistance are able to enter a new sector. They are then the origin of a new wave of copies that are able to spread throughout the sector until hitting the next higher antibiotics barrier.

So, again, mutations (or recombinations and any process which affects the genotype or the process of phenotypical development) only create a variety of solutions, which then are selected by the environment. If mutations were the driving factor and not just the provider of variety, evolutionary development would work without selection by the environment: life forms would develop independent of their surrounding nature. If from this random evolution life forms developed that were as adapted as we see in nature, this, in fact, would be like magic and the idea of a supernatural, driving force behind evolution would sound more rational.

The only time when mutations actually drive evolution is when the environment changes in a way that a certain trait is no longer needed by the life form. If it no longer matters if a life form does or does not have a certain gene, any mutated version of the gene has the same probability to be selected or not. Over time, more and more mutations accumulate until the original gene has become more and more rare and ultimately disappears. An example of a purely mutation-driven evolution is an *atavism*. For example, sometimes, children are born with tails because the combination of the parents' genetic remnants of a tail lead to a half-working copy of the genetic information of this limb of our distant ancestors.

1.2.7 "Macro-evolution"

While there is certainly enough literature on that idea in the *fiction* department, there is little evidence for the idea of "macro-evolution" in the real world but a whole number of arguments against it. First, there is no need for macro-mutations: all our organs can be explained by small evolutionary steps instead of large leaps. Second, any larger change to the organism affects all the parts of the organism which then have to be optimized again.

Imagine replacing the engines of an airplane with new, much larger ones. Sure, they are "better," but now the wings have to be changed and the whole model of the airplane has to be redesigned, too. Not to mention the changed fuel consumption, or the change of the maintenance procedures. That "better" plane would probably not take off from the ground. Sure, after some iterations of optimization it might, but nature does not have the luxury to wait for a few generations until an organism is "tested" in the environment. Every single iteration has to be good, as evolution cannot back-track.

Turning the question about macro-mutations around, how did we acquire abilities that were only possible with multiple changes to the whole organism? For example, for spoken language, we need a specialized brain, a specialized throat and mouth, the ability to control our breathing, and language itself. If just one thing were missing, any of these changes would be worthless. Or would they?

One argument *against* evolution is that for such (and many other) functions, we needed large jumps to accomplish them. Basically, they look as if a designer knew what he or she was doing and created individual parts that fit perfectly together. With this "designer," organs could evolve in anticipation of a newly desired trait in a later generation.

To argue against this point, it is necessary to understand how new traits can be added to an organism. The process of evolution at no point has the capability to "prepare" anything for some later generation, it needs to work now. In reality, it works the opposite way: evolution moves toward the point normally until all the conditions are right, and then a number of mutations combine the different existing abilities into a new one. Each step on the way contributes to a better organism, and each new generation afterward optimizes the newly found ability.

The point is that traits can develop even when there is neither a supernatural driver "directing" evolution, nor a specific requirement by the environment that puts a population under evolutionary pressure (like a predator). For example, spoken language certainly helped our ancestors, but it only started to actually develop once all the requirements were available. In biology, this is also called *exaptation*.

> **EXAPTATION** · *Exaptation* is the use of a certain trait for a problem or environment other than what it was originally "intended" for. An example would be feathers that started out as heat insulation, and only later were used to improve jumping, and finally for flight.

In technology, this can also be seen with 3D graphic cards: 20 years ago, when the first 3D accelerator cards came to market, nobody thought about using them for complex problems of astrophysics, biochemistry,[6] cryptography, or the "mining" of virtual currencies. These functions piggybacked on the success of 3D gaming until the cards were so advanced that they could be used for other applications.

When examining the details, life looks anything but "designed." There are too many strange design decisions, for example that the

[6] California, 2012.

nerves of our eyes sit above our retina instead below it. This leads to us having a blind spot where the nerves lead back toward our brain. A designer would have done it the other way around, like it is in octopus' eyes.

Likewise, nobody started out designing a 3D graphics card with the purpose of mining virtual currencies. Twenty years ago, that idea alone seemed ludicrous on multiple levels. But looking only at the present, the different technologies fit very well together, as if someone had planned out the whole thing from the beginning. In reality, the "planning," for example in product development, usually leads to a product that looks very much "unplanned" and clunky. Hence, there is currently a transition going on away from classical planning from start to finish, and toward a more "agile" management method with many iterations. The reason this can be better is that during the development process, a company learns a lot of new things about a product, and the market and general environment change, too.

Looking at it from a different perspective, if we gave a truly good designer the task of creating plants that would still exist in 500 million years, the designer would rely on the theory of evolution. The designer would have no way to predict how the world would change over the course of 500 million years, so any form of "planning" would be fruitless. Instead of actually designing the biology of the plant, the only chance is to give it the ability to adapt to its environment.

In that regard, it is important to note that life on Earth is far from stable. We know of several extinction events in the last 500 million years that caused massive reductions (50–95%) in biodiversity within a relatively short time. Each event allowed species previously living in small ecological niches to become the most dominant species. For example, as a result of the Triassic-Jurassic event 200 million years ago that was probably caused by massive volcanic eruptions, all *archosaurs* but crocodiles and the bird-like *avemetatarsalia* from which stem all of the dinosaurs we know of became extinct.

Likewise, 65 million years ago, a massive asteroid impact near today's Mexico caused the Cretaceous-Tertiary event which caused the extinction of the dinosaurs and gave rise to mammals. Other possible causes of massive extinction events are climate change, gamma radiation bursts of nearby supernovae, or life forms like the bacteria who first produced then-toxic oxygen, or terraforming humans today.

While we see massive changes of the ecology on Earth during these events, our previous discussion still holds. The changes are *shifts* not *mutations* within the populations. Suddenly, a single rare gene might have been the crucial factor that determined survival, so whatever other genes that individual organism had would spread as well. It is not so much that evolution made a "jump." It is simply that the environment and the factors influencing the evolutionary selection suddenly changed. This led to species on the fringes of the ecology suddenly becoming the most adapted species within their environment. These massive extinction events underscore that even under such circumstances, evolution still moves in relatively small steps.

1.3 The Evolution of Attention

What evolutionary steps contributed to the development of the conscious experience and process of decision-making humans possess today?

Figure 1.2: What we most closely connect to someone's attention are his eyes. Not only can the eyes tell us what someone is looking at, but they can also give us hints about what someone might be thinking (image source: Shutterstock).

> **ATTENTION** · *Attention* is the brain's process of limiting alternative thought patterns, then increasing the most dominant thought pattern's strength. It is like a simple majority rule: the most successful thought pattern gets all the resources while other thought patterns are suppressed. While we can jump back and forth between different thoughts, we cannot have two dominant thought patterns at the same time.

Attention refers to the ability to select between competing or even contradicting sense data. For example, you hear something on your left, see something moving on your right, you are hungry, and tired; which sense data gets your attention first? The brain parts involved that help us make such a decision underwent half a billion years of evolution and can be traced back to simple multi-cellular organisms.[7] Figure 1.3 shows the evolutionary timeline of primates with different species branching off. As we are looking only at the evolution of attention, our focus will be a small selection of species rather than a comprehensive discussion. Figure 1.4 shows the same tree of dependencies in a graphical form, with branches representing the creation of new major species.

Time	**Species**	**Brain part**
600 mya	sponges	calcium signalling
580 mya	*Hydras*	basic nerve net
550 mya	arthropods	information classification
535 mya	lancelets	olfactory system
520 mya	fish	optic tectum (information tracking)
520 mya	fish	thalamus (information integration)
520 mya	fish	basal ganglia (resolving conflicts)
520 mya	fish	amygdala (information evaluation)
520 mya	fish	hippocampus (spatiotemporal memory)
450 mya	sharks	cerebellum (movement programs)
300 mya	reptilians	wulst (high-level processing)
225 mya	mammals	neocortex (similar to wulst)
55 mya	primates	prefrontal cortex (planning)

Figure 1.3: Timeline (in million years ago) of the evolution of attention in animals with a list of species that branched off the evolutionary tree and the brain part that first appeared at that time.

[7] Kaas, 2017, p. 547–554.

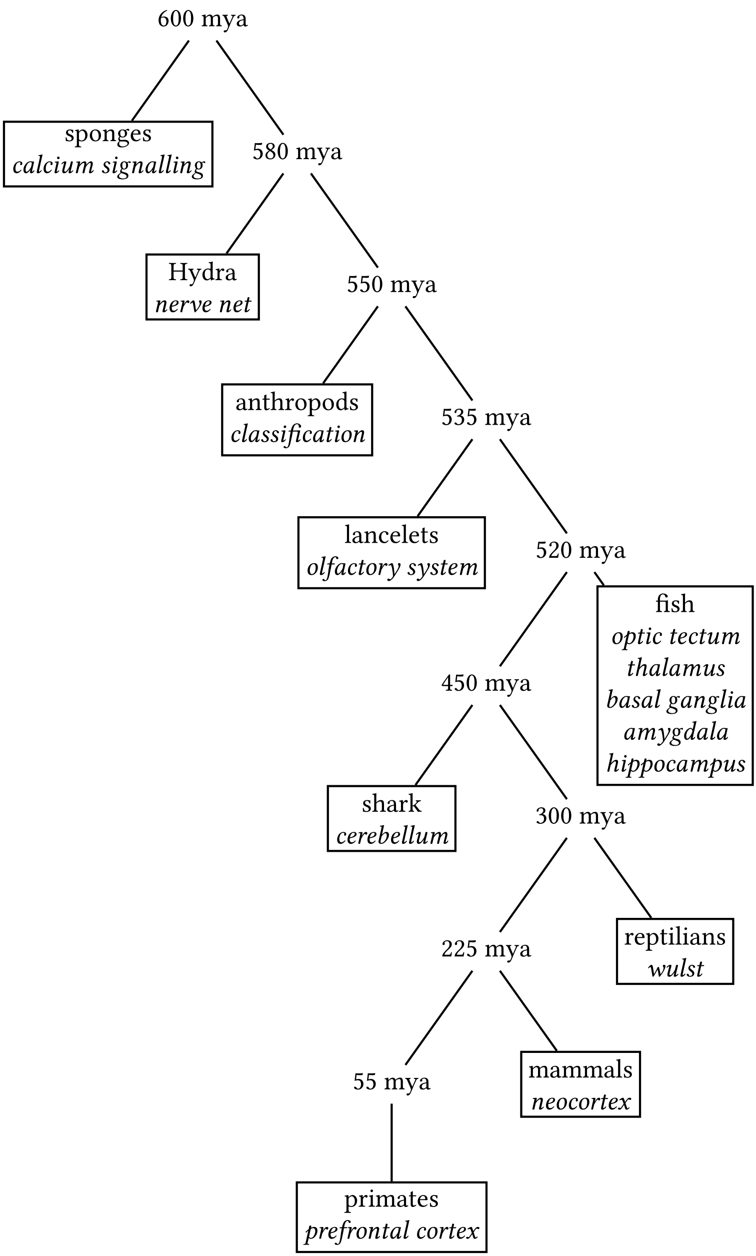

Figure 1.4: Simplified evolution of attention in animals.

Over this long history, the brain became a collection of different functions, layered on top of each other, with many systems having overlapping responsibilities. If a neural pathway helped one of your ancestors to avoid danger, that pathway survived, even if that meant that the architecture became somewhat chaotic ("complex").

Nature does not care about an easy-to-understand architecture; it cares only about what works and what does not.

Sometimes, the organization of a certain function into clearly distinct brain parts had an evolutionary advantage (for example, separating the *neocortex* from the rest of the brain). In other cases, the most efficient layout was having one function directly beside the other (for example, the different brain regions within the necortex). Yet, for our understanding of the brain, it is sufficient to look at it as a system of separate parts interacting with each other. We just have to keep in mind that the functions of brain parts usually blend into those of neighboring brain parts, and that there are many more interactions and connections between brain parts than listed here.

Major structural components and properties of the brain include:

> **ALLOCORTEX** · The *allocortex* is part of the cerebral cortex (the *neocortex* is the other part) and consists of the olfactory system and the hippocampus.

> **NEOCORTEX** · The *neocortex* is the newest part of the mammalian brain and consists of the *cerebral hemispheres.* Its main tasks are focus, language, long-term planning, and modelling of the world. It can generate strategies that involve detours if goal-directed behavior is not successful (for example, going around a fence instead of trying to get through it).

> **CEREBRUM** · The *cerebrum* includes the neocortex (the cerebral hemispheres), and the allocortex (the hippocampus, the basal ganglia, and the olfactory bulb).

CEREBRAL CORTEX · The *cerebral cortex* is the outer layer of the cerebrum. It contains most of the neurons of the brain.

GYRUS · A *gyrus* is a fold or ridge in the cerebral cortex.

SULCUS · A *sulcus* is a groove in the cerebral cortex.

1.3.1 Nerve Nets in Hydras

Looking at our tree of animal ancestors (see Figure 1.4) in regard to brain development, sponges were the first to settle into an evolutionary niche (more than 600 million years ago). They are sea animals that are mostly immobile and simply filter oxygen and nutrients from the ocean water. Although they have a primitive way of pushing water, when it is toxic or otherwise polluted, out of their bodies, they lack any form of nervous system as we understand it. Their cells communicate directly with each other using calcium signalling. Each cell contains a concentration of calcium that can be released if it receives calcium from neighboring cells. This way, it creates a calcium wave propagating throughout the organism. You can imagine it like having many square containers grouped together and filled to the brink with water. When you take one container and pour it into its neighboring containers, all the containers will overflow.

The first animals with some semblance of a brain were *Hydras*. They branched off our evolutionary tree more than 580 million years ago. They are small (around 10 millimeters in length) animals that usually attach themselves to the surface of an object in their environment and can slowly move over it or detach themselves and float in the water. They have a basic nervous system that allows them to use their tentacles to attack prey. If another animal (mostly tiny planktonic crustaceans like *Daphnia* or *Cyclops* up to five millimeters in length) touches a tentacle, the nerve cells activate the tentacle to take that animal into the *Hydra*'s mouth. There is no central nervous system that organizes this activation. Instead, nerve cells are spread throughout the body of the *Hydra* in a nerve net. This enables the *Hydra* to respond to its environment without being able to detect where this original stimulus came from. Any signal leads to the same reaction—for example, all muscles contract at the same time.

If the human body had a nerve net instead of a nervous system and brain, we would not be able to figure out where we were touched, only that we felt *something* and as a result had to come up with a general response to this touch. Such a general response is comparable to our hormonal system: for example, the adrenaline released in a situation of danger does not cause specific actions but prepares the whole body for a possible injury or energy exertion. Another example would be the regulation of body temperature which, again, is a general response to certain conditions instead of a specific movement.

1.3.2 Classification of Signals in Arthropods

A basic form of attention appeared at the time the arthropods (insects, spiders, crabs, etc.) split off the evolutionary tree around 550 million years ago. With this new form of attention, instead of treating all sensory input as equal, the information is pre-processed and can thus be amplified and classified. Imagine noticing something suddenly moving in the grass—it immediately draws your attention. Once you see it emerging from the grass, you classify it as a particular concept, for example, a snake.

At its core, classification is about *filtering* information we do not need. No longer would every signal cause a reaction. Instead, the organism was able to focus on specific signals and react to those.

Dog at 1pm	**Dog at 2pm**	**Analysis**
Basket	Basket	Dog has not moved
Rug	Rug	Dog has not moved
Basket	Rug	Dog has moved
Rug	Basket	Dog has moved

Figure 1.5: Example for an application of the XOR filter. If the dog is at different places at 1pm and 2pm, we can conclude that the dog has moved.

Most multi-layered nervous systems (including our own) support this kind of filtering. By comparing several images on your retina for changes, your visual system can make out which moving part belongs to which previously seen part. For example, if your visual system identifies a dog and then the same dog in subsequent images, you perceive any changes in those images as movements of the dog. If you closed your eyes every second, you would perceive the dog "jumping" from place to place. You would have to use your short-term memory as a workaround and remember where the dog was earlier to decide whether or not he had moved. Figure 1.5 shows an example that represents the function *XOR* ("eXclusive OR") which filters out similarities and returns differences. When passing two images through such an XOR filter, it would highlight changes between both images and thus detect movement.

Visual pre-processing is done partly by the retina of our eyes, detecting edges and changes, and compressing the data-stream toward the rest of the visual system. To understand what is happening, imagine looking at a picture of a palm tree in front of a white background. The brain perceives the detailed raw image, then the visual system extracts the edges of objects to identify them (see Figure 1.6). This way, the brain can determine that there is the shape of a palm tree. This is the opposite of what happens when *drawing* a picture: we *start out* with the palm tree in mind, then draw the edges and contours and then finally fill them in with details.

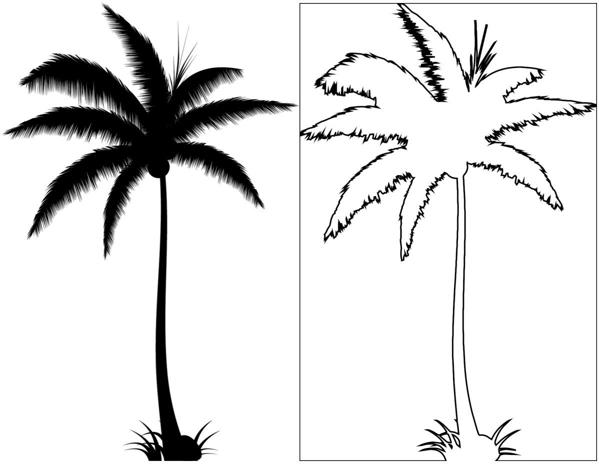

Figure 1.6: Edge detection applied to the image of a palm tree (image source: Shutterstock).

Beyond being just a one-way street of information (classifying the image data to abstract information), classification systems can also help you to direct attention. When we see things that are new or unusual, our brain allocates resources to finding out what they are. This could play out by turning our head, refocusing our eyes, looking at things from a different perspective, going closer, or asking others about the new or unusual things.

1.3.3 The Olfactory System in Lancelets

The olfactory system was probably one of the earliest sense organs that evolved in animals, as detecting molecules is closely connected to a lifeform's search for nutrients. While not directly related to us (they diverged from our ancestors around 535 million years ago), we share some of our olfactory-related genes with lancelets (see Figure 1.7). They can be seen as predecessors of fish with similar organs

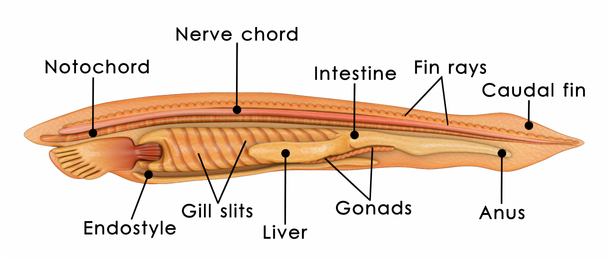

Figure 1.7: Lancelets can be seen as predecessors of fish with similar but more primitive organs (image source: Shutterstock).

but in more primitive form. For example, their gill-slits are used for feeding but not for respiration. Likewise, their circulatory system transports nutrients but not oxygen. While they have no centralized olfactory system (we humans do), their olfactory receptors are studded along their flanks to detect possible sources of nutrition in their aquatic environment.

Molecules connect to the olfactory system over the peripheral olfactory system. In aquatic animals, this happens directly via contact with the water. In land animals with lungs, this happens by having the airborne molecules dissolve into mucus on top of the olfactory receptor cells. If the molecule binds to the receptor cell, a nerve signal is created and transmitted to the brain. A peculiarity of our sense of smell is that it is the only sense that can bypass the thalamus (see Chapter 1.3.5) and send signals directly to the neocortex.

While our sense of smell might seem to play little to no role in our modern hectic life, it actually has a significant impact. In combination with our sweat, our sense of smell can communicate emotions. Usually, we think of emotions being contagious by way of our sense of sight or sense of hearing—we tend to laugh when we see or hear someone else laugh. But studies have shown that emotions are also contagious via our sense of smell. This works even when the smell is separate from the person (for example, on his clothes). So, even without words or gestures, people can communicate their distress to others nearby.[8] The evolutionary advantage of this mechanism makes sense, especially when it comes to fear. Putting yourself into a heightened state of alertness when detecting fear in other people can increase your chances of survival.

The olfactory system also supports mate selection by detecting pheromones which contain the MHC complex. It is relevant in the immune system's ability to differentiate self from other. In mate selection, a similar system is used to find a partner that is genetically not too similar but also not too different. The evolutionary advantage is to have a compatible partner with increased resistance to infectious diseases by providing a variability in the MHC complex.[9] At the same time, it reduces the chance for children to inherit genetic diseases. Similar to the immune system, the olfactory system probably becomes accustomed to the MHC complex of relatives in early childhood. If this contact does not happen, there is no biochemical obstacle to falling in love with close relatives.[10]

In terms of brain architecture, information travels not only from the olfactory system to the brain, but also in the opposite direction. If a particular faint smell wins the neural competition, resources are allocated to enhance our olfactory system's sensitivity. This focus can improve the olfactory system's efficiency by providing context information. In fact, the information from the millions of odor detectors in the olfactory system never even arrives at our neocortex. Instead, it is condensed into only 25 cells which are primed by the neocortex. If there is a strong smell, the sensitivity of the cells is reduced; if we want to pick up a faint smell, we can increase the sensitivity.

[8] Mujica-Parodi et al., 2009.
[9] Ejsmond, Radwan, and Wilson, 2014.
[10] Potts and Wakeland, 1993.

By combining the gustatory system (the basic tastes sensed by the tongue like salty, sour, bitter, umami, sweet, kokumi, calcium, and so on) with the smells detected by our nose, we can enhance our overall experience of food. Children learn to like or dislike certain types of food when observing what is safe for other people to eat.[11] While individual exceptions exist, if humans were genetically disposed to favor a particular food (like Koala bears prefer eucalyptus tree leaves) to the exclusion of other foods, our ancestors would have had a hard time spreading all over the globe.

If the olfactory system classifies something as inedible, it might initiate the gag reflex to protect the body from poisons. If we actually get food poisoning or an infection, the body reacts by increasing acetate levels in the blood. In the brain, this improves the ability to create memories. The evolutionary advantage of this pathway could be to better remember the situation that led to the food poisoning or infection and thus prevent it in the future.

All these properties are reflected in the architecture of the olfactory system. There are the following connections (Figure 1.8):

- Trigeminal nerve, vagus nerve (gagging reflex, face muscles, expression of disgust);
- Hippocampus (spatial memory);
- Amgydala, hypothalamus (emotional reaction, hormones, pheromone processing);
- Neocortex (processing of smells);
- Hippothalamus (pheromones, hormones);
- Olfactory bulb (sensory cells); and
- Nose (air flow).

[11] Elsaesser and Paysan, 2007.

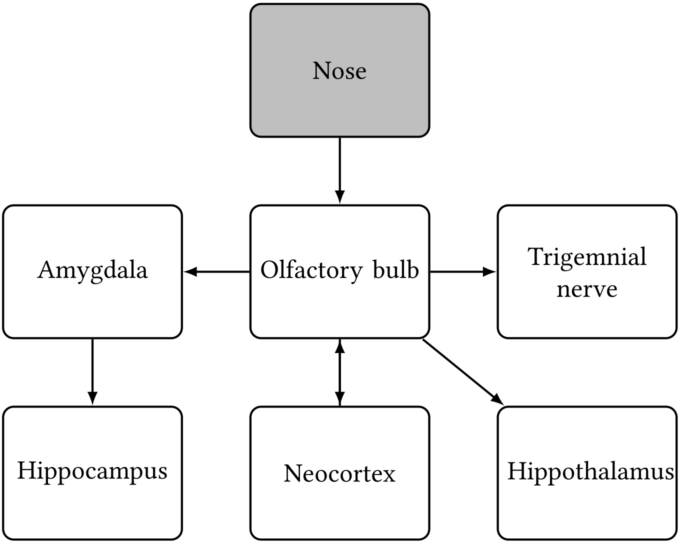

Figure 1.8: The architecture of the olfactory system.

1.3.4 The Optic Tectum in Fish

Controlling eye movements made it necessary for fish (they split from the evolutionary tree around 520 million years ago) to develop central processing, namely the *optic tectum*. In mammals, this organ is called the *superior colliculus* and most of the processing has moved to the visual cortex. It helps fish (and us) to track moving objects and is responsible for blinking as well as pupillary and head-turning reflexes. Relying on auditory information, the superior colliculus is also responsible for reflexively turning one's eyes and head toward a sound source.

In the brain, the superior colliculus sits right behind the optic chiasm where the nerves from the left eye and right eye cross. If something or someone outside of your eyes' focus moves, this part of the brain is responsible for bringing it to your attention. You might then turn your head and re-focus your eyes to get a better picture of the possible threat. Imagine you did not have this reflex to see anything moving in your environment. The risk of injury (say, from an oncoming tiger) would be much higher because of your longer reaction time.

> **Superior colliculus** · The *superior colliculus* or *optic tectum* (in non-mammals) helps the eyes to track objects, and controls blinking, pupillary, and head-turning reflexes.

1.3.5 The Thalamus in Fish

On the evolutionary timeline, the *thalamus* also first appears in fish. It combines and pre-processes different sources of sensory information into a coherent whole before relaying it to other parts of the brain:

- It combines the information from the left eye and right eye to build a three-dimensional representation of the environment.
- In humans, it translates the signals from the red, green, and blue cone cells in the retinas into colors. While further processing takes place in the neocortex, the first part responsible for this color encoding is the *lateral geniculate nucleus* (or LGN).
- Like the superior colliculus, the LGN also receives auditory information. The LGN changes the auditory information so that you perceive the sound as coming from a visual source. For example, when watching television, the LGN "moves" the perceived location of the source of sound from the speakers to the screen.[12]

[12] McAlonan, Cavanaugh, and Wurtz, 2006.

Thalamus · The *thalamus* integrates different sensory information and relays the information to other brain parts. For example, it combines sense data from the retinas' cones into colors, or calculates three-dimensional information from the two-dimensional images from both eyes.

Lateral geniculate nucleus · The *lateral geniculate nucleus* (LGN) is part of the thalamus and relays information from the retinas (via the optic chiasm) to the visual cortex. It pre-processes some of the information, for example, combining red, green, and blue photoreceptor cells into colors.

1.3.6 The Basal Ganglia in Fish

Neurons form a network of small biological computers. We can compare a network of neurons with a political committee where each member votes on particular issues. The result of the entire committee leads to an action of which we might become aware. Neurons receive an electric input, can do some basic calculation, have properties that influence the calculation, and have an electric output connecting them to other neurons (or, ultimately, muscles). In addition, neurons have receptors to communicate with the body's hormonal system.

In political committees, beyond just voting, the committee members are also engaged in promoting their views to other members. In the context of our brain, the neurons can recruit connected neurons by adapting their activation patterns. Those recruited neurons themselves recruit other neurons, too, until a significant portion of neurons are firing the same thought pattern. This thought pattern "wins" the competition by sheer numbers and thus a decision is made.

How well neurons can be recruited depends on the mind's "landscape," which is determined by the person's experiences, memories, sense input, hormonal state, and genetics. In this landscape, thought patterns compete to gain dominance. In "niches," less "popular" thoughts wait for their time of day, defending their place from other thought patterns that did not adapt to these "experience niches." It is like a jungle, home to many different "experience organisms" that come out only when we have an experience connected with it, like a familiar smell, sound, or image. Each thought pattern has to try to survive and adapt in its environment consisting of other thoughts and memories. As the terms (landscape, jungle, organisms,...) suggest, what is going on in the cortex resembles evolution in nature, just at a much faster pace.

For this evolutionary competition of neurons to work, research points to an involvement of the basal ganglia.[13] The *basal ganglia* are thought to originate from the need to arbitrate between different courses of motor neuron activation. They identify the "best" among several possibly contradicting courses of action. Rules determine what "best" means in a particular context. For example, you can have the two competing thoughts (e.g., wanting to go left and to go right), but you cannot physically walk in two directions at once.

> **BASAL GANGLIA** · The *basal ganglia* are a part of the brain that, like a referee, arbitrate decisions by the neural committees. Also, like an orchestra conductor, they coordinate the sequence of entire motor programs. In both cases, they do not make decisions but merely provide rules and structure.

Beyond selecting individual motor actions, the basal ganglia seem to be involved in cognitive thought patterns. While contradicting thoughts can exist, different thought patterns cannot recruit the same cognitive resources at the same time. For example, imagining a unicorn leads to thought patterns recruiting parts of your visual

[13] Redgrave, Prescott, and Gurney, 1999.

cortex. Adding more elements to the scene requires more and more resources until you can no longer focus on all elements at the same time. The basal ganglia are also involved in coordinating entire motor programs. Imagine an orchestra without a conductor: sure, the musicians could play their respective parts, but at different speeds and starting at different points in time. The basal ganglia act like a conductor of an orchestra, synchronizing the different motor programs, activating them in the right sequence and with the right timing.

1.3.7 The Amygdala in Fish

Yet another brain part, the *amygdala*, first appeared in fish. Managing our attention with the basal ganglia is one thing, how we *prioritize* the signal is another. While we can make decisions based on the strength of the signal—turning our head to the loudest noise seems to be a good strategy—we also need to put the signal into context. For example, instead of always running away from a tiger, we might consider whether or not to take the risk and first pick some berries and only then run away—especially if we are very hungry. This demonstrates how the amygdala uses information from a number of sources to prioritize different courses of action.

> **AMYGDALA** · The *amygdala* is the brain's value and emotion center. It helps with evaluating thought patterns of the basal ganglia depending on the context instead of the mere strength of the signal. It also connects the brain with the hippothalamus, providing a bridge to the hormonal system.

With its connection to the hormonal system, the amygdala also initiates fight, flight, freeze, or fawn responses when in distress:

- Attack the predator ("fight" response);
- Run away from the predator ("flight" response);
- Remain still ("freeze" response); or
- Display submissive behavior ("fawn" response, by humans and other social animals).

How the fight and flight responses can help in a threatening situation is self-explanatory. The "freeze" response can trick predators because many predators' instincts depend on motion. If their prey is not moving, the predator's hunting instinct is not activated and they will look elsewhere for food. For example, cats take great interest in a moving toy while they might ignore something that remains still. Similarly, the "fawn" response works if the attacker is from the same species and also a social animal. Showing submissive behavior communicates to the other party that you are not a threat, preventing possible injury for both parties.

Beyond helping with the immediate response (e.g., releasing adrenaline), it can also serve as an early basic form of memory. For the response to be effective, the hormonal changes caused by, for example, the flight response need to remain long after a predator has vanished from an animal's view. It will cause it either to head home to a safe place or to be on alert when it returns to this location.

The information the amygdala is using is limited to immediately available sensory data. It activates emotional reactions based on mapping the input from the thalamus to emotional behavior. For example, the sight of fresh berries might evoke a positive emotional response while the sound of a rival might evoke a fight, flight, or fawn response. This response takes priority over any rational evaluation of the situation because it is quicker and possibly stronger than signals coming from the neocortex. The amygdala associates sense data coming through the thalamus with positive or negative events and, ultimately, emotions, for example:[14] Tiger $\Rightarrow$ fear; apple $\Rightarrow$ appetite; and sun $\Rightarrow$ happiness. What makes this mechanism so powerful is that it requires very little processing power while it can cover a wide range of sensations. The major limitation of behavior based on the amygdala is the limited range of reactions and the reliance on immediately available sense data. The amygdala cannot take into account abstract thinking or planning, or complex relationships between objects, animals, or people.

1.3.8 The Hippocampus in Fish

A predecessor of our *hippocampus* also developed around the time of the first fishes. The actual hippocampus is unique to mammals but there are theories that similar structures evolved from a common ancestor of reptiles and mammals around 520 million years ago. Its main task is to create a mental map of an animal's environment to allow the animal to remember where possible food and water sources are located. It also helps with navigation, remembering paths the animal has taken, relating spatially to other animals or objects,[15] and recognizing places for orientation. A good example for the use of the hippocampus is squirrels burying nuts as food stashes for the winter. Our current understanding is that this map is not a literal map but instead consists of points of orientation. While many people can construct a mental image of a map, we tend to orient ourselves by seeing something we know and then putting our goal in relation to the landmark. For example, when describing to another person the path to a location, we might say "Walk down the street until you get to the large tower, then turn right."

[14] Tye et al., 2008; Rogan, Stäubli, and LeDoux, 1997; McKernan and Shinnick-Gallagher, 1997.

[15] Danjo, Toyoizumi, and Fujisawa, 2018.

Hippocampus · The brain's *hippocampus* provides us with a mental map for navigation. It also builds temporal relationships between places, allowing us to determine, for example, which areas in our environment we have already foraged and in which areas the plants have regrown. The *hippocampus* and the *olfactory system* (sense of smell) make up the *allocortex*.

While earlier animals could drift and react to sensory inputs (evading predators and approaching food), once the food was out of sight, it was also out of mind. The hippocampus allowed animals to find more food by avoiding areas that they had already foraged and exploring areas they had not foraged. This requires mapping the environment based on odors (the sense of smell has direct connections to the hippocampus) and sights, as well as prioritizing those according to the time they should be visited.[16] This led to the evolution of the hippocampus to handle tasks in serial order with the right timing and in the right context. This stems from its ability to associate two memories with each other, which helps to find a path from one place to another.[17]

The hippocampus' function becomes most visible during dreams, when experiences retained during the day are played back for long-term memory backup in the neocortex. While we cannot ask animals whether or not they dream, some animals show rapid eye movements (REM) in their sleep, pointing to an activation of their hippocampus.

[16] Murray, Wise, and Graham, 2018.
[17] Samsonovich and Ascoli, 2005.

1.3.9 The Cerebellum in Sharks

More than 450 million years ago, sharks with a *cerebellum* emerged. This organ coordinates complex, time-critical behavior which includes movements, speech, and balance. When hunting, the shark might have had to outmaneuver its prey and then bite at the right moment. Similarly, its prey had to come up with movement strategies to navigate through the water to evade predators, locking predator and prey into an evolutionary race. Mammals face similar challenges of coordination when trying to jump from tree to tree, evade attacks by predators, or catch prey. Given that both the cerebellum and the basal ganglia are involved in coordinating motor programs, it is no surprise that they also form an integrated network to exchange information.[18]

> **CEREBELLUM** · The *cerebellum* is the brain part that helps with coordination of complex behavior. It provides a set of motor programs the brain can choose from repeatedly for similar actions (even in time-critical situations). With the help of the cerebellum we can, for example, walk or bicycle without having to consciously think of each movement.

In more general terms, the cerebellum is responsible for replaying movements. This becomes apparent when examining how the cerebellum learns new movements. Think about how each leg moves, as you did when you first learned to walk or to ride a bicycle: the programs to coordinate all your motor neurons were not yet transferred to your cerebellum ("learned"). Thus, they were not yet optimized and consequently, they were very slow. Until that optimization happened, walking or riding a bike had not become "second nature." You had to take "baby steps" and focus on one step or motion at a time before making the next one.

[18] Bostan and Strick, 2018.

In the (very rare) case of people born without a cerebellum, we see late walking development, reduced gait speed, unsteady gait, and a reduced ability to stand in darkness or when their eyes are closed.[19] This is explained by the fact that the cerebellum is connected to the inner ear, providing our sense of balance. In addition, people born without a cerebellum have late speech development, slurred and slowed speech, and a reduced control of pitch and loudness. This points to an additional role of the cerebellum in language fluency.[20]

1.3.10 The Neocortex in Mammals

The neocortex, which is layered over the *collicular control* of attention (above the previously mentioned superior colliculus), developed more than 300 million years ago. Following the Permian-Triassic mass extinction event 252 million years ago (extinguishing 70% of land biodiversity), both the dinosaurs and mammals emerged. Given that dinosaurs still dominated the planet, mammals had to move into a niche and become nocturnal animals. According to the *nocturnal bottleneck hypothesis*, traits of growing fur, managing body temperature, and well-developed senses of smell, hearing, and touch helped our ancestors to stay active at night while evading predators during the day.

> **NOCTURNAL BOTTLENECK HYPOTHESIS** · The *nocturnal bottleneck hypothesis* posits that many mammalian traits were adaptions to moving into a niche to become nocturnal animals and evade the dominant dinosaurs.

Functions of the neocortex include sensory perception, conceptualization, directed motor commands, spatial reasoning, communication, and long-term planning. The visual field is analyzed to create a mental representation of objects and their location. Instead of the

[19] Yu et al., 2014.
[20] Carta et al., 2019.

raw sense data, this mental representation of the world is then used by the rest of the brain in, for example, coordination with motor control, language (reading this book), or face recognition. Similarly, other senses (hearing, touch, smell, etc.) are processed, and their signals are categorized and prioritized.

While we are now aware of the principal brain functions we share with other mammals, the question remains what makes us humans unique. In Chapter 1.4, we will look at how our human ancestors adapted to the Savannah and how that set them apart from their closest primate cousins, the chimpanzees, that stayed behind in the forest.

1.4 The Rise of the Primates

To understand human nature, we can compare ourselves with our closest primate cousins, the chimpanzees. How do we differ, what makes us special, and what has taken us on two different paths?

Some 66 million years ago, a 10km- to 15km-wide asteroid hit what we today know as the Gulf of Mexico and in its aftermath killed all animals over 55 pounds body weight (the *Cretaceous-Paleogene extinction event*). This opened an opportunity for the smaller mammals to slowly return from their nocturnal life. Prior to this fateful event, mammals had adapted by hiding during the day. At night, they relied on their sense of smell to evade predators and to locate prey. This led them to evolve abilities that turned out to be useful when they returned to the daylight. One of those abilities was suppressing immediate urges. With the help of the *prefrontal cortex*, the mammal was able to save valuable time and energy. It could ignore scents of predators that were long gone, and pursue prey that was still nearby.

> **Prefrontal cortex** · The *prefrontal cortex* is part of the frontal lobe and can be understood as running a simulation of the world. It monitors social relationships, keeps track of objects when they are no longer visible (object permanence), and helps with the pursuit of long-term goals. It has only indirect connections to brain parts dealing with actions or sense perception.

When mammals later adapted to the daylight, the same principle was applied to visual data. For example, just seeing a lion does not mean that the lion is dangerous; it might be sleeping. To make that judgement call, the separate evaluation and signal by the prefrontal cortex was needed as a counterbalance, thinking long-term, balancing risk and reward.

The prefrontal cortex is only indirectly connected to any sensory organs or muscles, hence it is believed to process thoughts that do not need any external input to be activated and do not necessarily result in a concrete action to be executed. Put differently, the prefrontal cortex reads and controls the rest of the brain instead of directly accessing sense organs or muscles.

To understand the prefrontal cortex' role, we need to remember that many parts of the brain are in competition with each other. In that regard, the prefrontal cortex can be understood as a counterbalance to the rest of the brain. Applications include long-term goals, social rules, hidden threats, imagination, or memories. For example, a strong visual input like a tiger standing in front of us would need an equally strong competing signal to prevent a simple fight, flight, fawn, or freeze reaction.

1.4.1 The Primary Motor Cortex

The first true primate ancestor was a small nocturnal monkey-like, forest-dwelling animal (*Plesiadapis*) that lived in trees and ate fruit (around 55 million years ago). This primate-like mammal needed strength and balance to jump from tree to tree, and a brain that could calculate movement in three-dimensional space, as opposed to just navigating on the ground. Also, its eyesight had to improve to adapt to the light of day and to recognize ripe fruit. A testament to this evolutionary history is that we now lack the ability to produce our own vitamin C and need to rely on a steady diet of fruit and vegetables.

About 30 million years ago, the evolutionary branch split into Old World monkeys and New World monkeys. The most widely held theory about this split is that the ancestors of the New World monkeys used a temporary land bridge or series of islands between Afro-Eurasia and South America. The main difference between the two types of monkeys is that New World monkeys kept their tail. With their *primary motor cortex* (see Chapter **??**) being focused on their tail muscles, they use it like a fifth limb. In contrast, the primary motor cortex of apes (Old World monkeys) is specialized for hand use which helps with foraging for fruit. To observe this in humans, just stand in a modern supermarket and watch people carefully checking out the ripeness of avocados.

> **PRIMARY MOTOR CORTEX** · The *primary motor cortex* is part of the frontal lobe and is directly adjacent to the primary somatosensory cortex of the parietal cortex. This way, it can directly process data from our sense of touch to better control movements. The *primary motor cortex* connects to the *brainstem* and *spinal cord* (via the *upper motor neurons*) which in turn connect to the muscles (via the lower motor neurons).

The feature that makes the primary motor cortex in primates special compared to that of other mammals is that it can bypass the spine's interneurons (the spine's relay station) and send signals directly to the motoneurons of the spine.[21] With a significantly higher number of neurons controlling the movement, this allows fine-grained control of the actual signals sent to the muscles. This part of the brain also grew overproportionally during the evolution of primates.[22]

Why exactly do more neurons lead to better control?

Our primary motor cortex contains about 5 billion neurons controlling some 600 muscles. Those 600 muscles consist of more than 50 billion muscle cells. But muscles can only contract, so, theoretically, to contract all 600 muscles individually, no more than 600 motor neurons would be needed. Signals arriving in the primary motor cortex already contain the specific motor program, so all that is left for the primary motor cortex to do is to translate those into signals associated to individual muscles.

Let us imagine two extreme architectures:

1. **If any nerve detects a signal, all muscle cells contract.** This is the case with the nerve net in the previously discussed *Hydra* (see Chapter 1.3.1). As fewer motor neurons need to be activated, this option is extremely energy-efficient and quick: each movement could be done with maximum strength in the blink of an eye. Theoretically, you would need only a single nerve cell to control all muscles in your body. On the other hand, the only possible action you could take is to contract all muscles at the same time. Imagine you could fully exert your biceps with the same mental effort it takes to move your little finger. You would leave the gym with sore muscles but

[21] Rathelot and Strick, 2009.
[22] Rowe, Macrini, and Luo, 2011.

mentally, you would still feel refreshed. The downside is that you would not have any precision if all you could do is exert full force or exert no force at all.

2. **Each muscle cell is connected to an individual nerve cell coordinating whether or not it contracts.** A movement can involve any number of muscle cells in any combination and sequence, allowing very fine-grained control of the position of the limbs as well as the force exerted with each movement. This option is very energy intense, though. Not only would your body have to provide energy for your muscles to work, your nerve cells would take a similar amount of energy to operate the muscles. Our brain uses around 10 billion neuron cells to control 50 billion muscle cells. To reach a level of control where one neuron cell controls one muscle cell, our brain would have to be around 50% larger than its current size (our brain has around 86 billion neurons and would need around 126 billion neurons).

Our own primary motor cortex resembles the latter architecture more than the former. Compared to our more powerful cousins, the chimpanzees, our primary motor cortex is about 20% to 70% larger.[23] In chimpanzees, the relatively small number of motor neurons can be activated very quickly, allowing for greater strength. On the other hand, the higher number of motor neurons in humans allows for more precise movements and significantly less energy expenditure by the muscles. This gives us better control over how much force we want to exert—a crucial ability when it comes to using (or producing) more advanced tools like bows or spears.[24]

[23] Donahue et al., 2018.
[24] Walker, 2009.

1.4.2 The Rise of the Hominids

Further splits occurred about 15 million years ago (gibbons), 13 million years ago (orangutans), and 10 million years ago (gorillas), with the final split from chimpanzees and humans between four million and 13 million years ago. From there, we can trace back our human ancestors, with their most distinctive feature being a progressively increasing brain volume:

- *Australopithecus* (3.6 million years ago, 485 cm^3)
- *Homo habilis* (2.1 million to 1.5 million years ago, 650 cm^3)
- *Homo erectus* (2 million to 0.14 million years ago, 1100 cm^3)
- *Homo heidelbergensis* (0.7 million to 0.2 million years ago, 1230 cm^3)
- *Homo neanderthalensis* (250 thousand to 40 thousand years ago, 1500–1740 cm^3)
- *Homo sapiens* (today, 1425 cm^3)

With Neanderthals having had larger brains than humans, were they more intelligent than humans?

To answer this question, it is important to note that besides humans and their ancestors, other animals also have large brains. For example, bottlenose dolphins have a similar brain size as humans have. They have been observed helping out other dolphins as well as those of other species like humans (e.g., drowning divers), which points to them sharing our ability to understand what other beings are possibly thinking or experiencing.[25] But to compare brain sizes between humans and other animals, we need to include their *body size* into our calculation. Larger bodies produce a larger quantity of signals

[25] cf. White, 2007, p. 41.

that need to be processed and have more muscle cells that need to be activated. For example, while whales have a brain size more than five times that of humans, they are not necessarily quick (or creative) thinkers. They need that brain size to control the muscles in and the sensors of their huge body (around 50 tons). Thus, to get a sense about an animal's intelligence, we need to look at the total brain size divided by the body mass, and set it in relation to the average (for the species) brain size and body mass. This so-called *encephalization quotient* (EQ) provides such a mapping, making it possible to compare different animals' potential intelligence (see Figure 1.9).[26]

> **ENCEPHALIZATION QUOTIENT** · The *encephalization quotient* (EQ) is a measure of relative brain size and is often used to convey how small or large a species' brain is compared to that of other species of similar body size.

Species	**EQ**	**Cranial capacity**
Human	7.4–7.8	1250–1450 cm^3
Neanderthal	7	1600 cm^3
Bottlenose dolphin	5.3	1350 cm^3
Homo erectus	5	1100 cm^3
Homo habilis	4.3	650 cm^3
Eurasian magpies	2.49	5 cm^3
Australopithecus	2.5	485 cm^3
Chimpanzee	2.2–2.5	330–430 cm^3
Gorilla	1.5–1.8	500 cm^3
Whale	1.8	2600–9000 cm^3
African elephant	1.3	4200 cm^3
Dog	1.2	64 cm^3
Cat	1.0	25 cm^3

Figure 1.9: Comparison of different species' brain size sorted by their relative encephalization quotient.

[26] Roth and Dicke, 2005.

As the table shows, when accounting for their larger body mass, the encephalization quotient of Neanderthals is similar to that of modern humans. And it has been shown that Neanderthals created and used tools like spears, possibly had language, and developed their own cultures. *So, how do we differ from Neanderthals?*

We find a clue by looking at gorillas. With an encephalization quotient of 1.5, they are at the lower end of the EQ spectrum—while clearly highly intelligent given that they can learn sign language and make and use simple tools. This points to the EQ not telling the entire story. Hence, scientists have divided the brain mass further into parts necessary for the maintenance and control of the body and senses, and those associated with improved cognitive capacities.[27] Subsequent studies on Neanderthal brains[28] have shown that they must have had significantly larger eyes (possibly to allow better sight for hunting where there was not much light) than those of humans. Also, the brain part responsible for image processing must have been larger, which left less brain mass for social relationship processing. The currently accepted theory is that humans used their social intelligence as an advantage over Neanderthals, ultimately replacing them—even though the latter possessed better sight and body control. Research seems to point to multiple migrations from Africa to Europe[29] and back from Europe to Africa[30] with interbreeding over a prolonged timespan.

Further research needs to be done in regard to arthropods (insects, spiders, etc.) and cephalopods (especially cuttlefish, squid, and octopodes). For example, jumping spiders are able to plan ahead and to apply hunting strategies, and even care for and nurse their young like mammals do.[31] This is reflected in their brain-to-body ratio: a jumping spider's brain requires so much space that it is distributed

[27] Roth and Dicke, 2012.
[28] Pearce, Stringer, and Dunbar, 2013.
[29] Kuhlwilm et al., 2016.
[30] L. Chen et al., 2020.
[31] Z. Chen et al., 2018.

throughout its tiny body. Another example would be octopodes; they have two-thirds of their nervous systems in their arms, resulting in a brain-to-body quotient comparable to that of humans. Octopodes can use tools, solve puzzles, recognize people, and plan ahead.

In the case of some animals, to counter the size limitations of the brain, the brain uses *cortical folding* to increase surface area and processing speed.[32] Imagine that very early during embryonic development, the neurons form a flat plane and then fold while the surface area is growing. This is comparable to creating towels by adding loops of thread (the folds) to a piece of cloth. They increase the surface area of the cloth without increasing the size of the cloth (the plane). Trees solve the problem of capturing sunlight in a way that is similar to the brain creating folds: to maximize the exposure of leaves to the sun, the tree creates branches which subsequently create branches and so on. This way, the distance from each leaf to the trunk is limited, while maximizing the amount of sunlight the tree can capture (see Figure 1.10). Objects like these are called fractals.

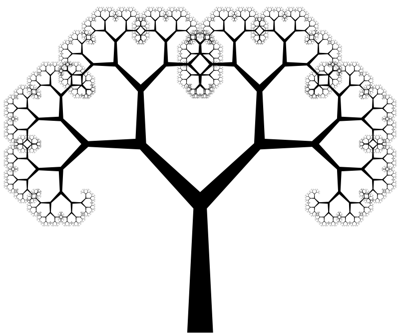

Figure 1.10: This tree-like fractal covers a potentially infinite surface area while limiting the distance from the leaves to the trunk.

[32] Striedter, Srinivasan, and Monuki, 2015.

1.4.3 The Rise of the Humans

How could larger brains have helped early humans to survive? After all, we apply most of our intelligence to utilize complex language and tools. But those things were not available to early humans. And compared to other mammals, even compared to apes, humans are neither strong nor fast, we do not have body armor, we do not have claws or poison, we do not have wings or a strong sense of smell, and we cannot see well at night. At the same time, larger brains meant a higher energy need. In that regard, the question of how human intelligence evolved looks like another chicken-and-egg problem. We need to find an evolutionary path of incremental genetic changes, benefiting our ancestors at each step.

We have become a complex product of nature because our ancestors had to adapt and re-adapt again and again to ever-changing environments. Compare that to lifeforms that have not changed significantly for hundreds of millions of years: they have found a niche in which there was no evolutionary pressure to adapt to new challenges.

The important lesson is that evolution does not work in a directed way where all lifeforms become smarter over time. Brains are simply an adaptation to very specific problems. Each part of our brain addresses a particular need to process information in order to give us an edge over our predators and prey.

Hence, one approach to the question of how humans have diverged from other primates is to think about the influence of the *environment* on our ancestors' evolution. The split from the chimpanzees four million years ago probably happened between those of our ancestors staying in the forest and those going out into the savannah. As trees provided protection and sources of food, it is possible that the savannah was not their first choice. Perhaps a change in geology or climate caused the forest to recede. Later, population growth might have driven our ancestors out into the savannah; this is the *savannah hypothesis.*

> **SAVANNAH HYPOTHESIS** · The *savannah hypothesis* states that early humans evolved on the savannah and that many of the modern human's traits are a result of this adaption.

While the precise sequence of events is still debated—more recent evidence points to a much less abrupt transition from forest to the savannah[33]—the following traits were conducive for early humans to survive in the savannah:

Fire and cooking. Fire allowed early humans to be more active at night. It provided warmth and helped to fend off predators. With the ability to control fire, early humans were able to cook food. This reduced the time needed for digestion compared to eating raw foods, freeing up energy for the brain. While in other apes, the colon represents about 50% of gut volume, in humans, it is less than 20%.[34]

Bipedalism. Bipedalism probably developed before our human ancestors moved into the savannah. After all, apes are able to walk on two feet; they typically choose not to do so. Their muscle configuration makes walking less energy-efficient when compared to humans—just like we *could* walk on our hands, but it takes far too much energy.[35]

Endurance. Better muscle control due to the larger motor cortex (see Chapter 1.4.1) allowed our ancestors to travel longer distances —a very advantageous trait for living on the savannah.

[33] Domínguez-Rodrigo, 2014.
[34] Furness, Cottrell, and Bravo, 2015.
[35] Sockol, Raichlen, and Pontzer, 2007.

Cardiovascular system. We see additional optimization toward endurance in our heart which has adapted for moderate-intensity activity like walking, hunting, or farming. (By contrast, chimpanzees' hearts are optimized for short bursts of intense activity such as climbing and fighting).[36] This enabled our human ancestors to cover greater distances in the savannah, spreading their genes with tribes farther away. And while we cannot run faster than a cheetah in a sprint, we can outrun it in any hunt longer than a mile. Cheetahs are all about sneaking close to their prey and then sprinting toward it in one short burst.

Sight. In the forest, chimpanzees' main visual focus is spotting details. The global image of the forest as a whole is less important than identifying, for example, a snake, or fruits, or another chimpanzee hiding among the leaves. By contrast, the focus of humans adapted to a life in the savannah is a more comprehensive, global image. To coordinate a hunt, you need to keep your entire environment in mind and create a plan for how to approach prey from different directions. Studies have shown that humans are much better than other primates at integrating local visual information into a global whole.[37] Also, being on watch for predators or coordinating a hunt requires humans to constantly scan all directions. The anatomy of our eye sockets gives us a wider field of view compared to that of chimpanzees.[38] This is also more economical as we have to move only our eyes rather than our entire head.

Ranged weapons. It takes precision and perseverance rather than explosive strength when looking at an animal from a distance, feeling the wind, taking a wooden spear, calculating which of the dozens of muscles to stretch and release and in what sequence so that the stick hits its target, and then tracking the wounded animal over hours. In order to throw accurately, the brain has to calculate

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[36]Shave et al., 2019.
[37]Denion et al., 2014.
[38]Imura and Tomonaga, 2013.

a sequence of nerve pulses to coordinate which of the hundreds of muscles should contract and in what order. To maximize the impact of a throw, the muscles have to work in harmony, just as performers in an orchestra play various instruments and create a harmonious sound. The comparison between throwing a spear and playing music is fitting as the same regions of the brain are used to produce both. While ranged attacks can be found in nature (tongues of chameleons, other primates throwing sticks and stones, archerfishes spitting water at bugs, pistol shrimps "shooting" air, jumping spiders jumping at their prey), humans are the *only* animal in nature to accurately throw things at long distances.

Language. Building a sentence requires advance planning and coordination. We need to use words in a specific order to carefully construct the sentence rather than trying to exert ourselves in one loud call. This uses the same mental machinery that is required to accurately throw. The *cognitive trade-off hypothesis* explains this difference between chimpanzees and humans by stating that our human ancestors exchanged (some of) their short-term memory for other abilities like abstract language and planning. Evidence for this is in (compared to chimpanzees) humans' significantly larger *angular gyrus* (see Chapter **??**), which helps with tool use, reading, and language.[39] It is also home to our working memory (at least the phonological memory), which is superior in humans compared to chimpanzees.[40]

Reaction time and memory. While humans indeed require short-term memory for conversation, remembering telephone numbers, and reading, only a minimum amount is needed. Not only is a conversation—compared to the snap decision a chimpanzee has to make —stretched out over an extended period of time, but there is also always the possibility of asking questions.

[39]Fjell et al., 2013.
[40]Read, 2008.

Our ancestors in the forest faced a situation very different from those who went out in the savannah. In the forest, with trees blocking their line of sight, they had less time to react to sudden encounters with predators (or rivals). At the same time, they could use the trees to flee from their predators. This adaptation to quickly evaluate and react to a situation seems to be reflected both in today's forest-dwelling chimpanzees' strength as well as in their (compared to humans) superior short-term memory capacity. Experiments have shown that some chimpanzees need only 0.21 seconds (compared to humans needing at least 0.65 seconds) to remember the position and sequence of nine numbers on a computer screen.[41] This is similar to what a chimpanzee might encounter in the wild: imagine nine rival chimpanzees showing up. For the one chimpanzee defending itself, each second spent determining whether to flee to the trees or to prepare to fight might determine whether or not the chimpanzee loses territory, is injured, or even killed.

Games. Language also allows more educational *play*. While other animals (for example dogs or their puppies) have ways of signalling they want to play-fight, humans can develop much more complex games (e.g., hopscotch, fencing, martial arts, soccer, chess, etc.) to allow them to train their mental and physical abilities.[42] We can even use play productively: for example, we train people to operate in space while they are still safely on Earth.

Complex tool use. The mental machinery required to process language also allowed us to create complex tools. Sentences consist of subjects, objects, verbs, adjectives, and adverbs that connect with or modify each other. Similarly, tools consist of different objects that need to be connected. If you can imagine sentences that describe how entities interact with each other, you can imagine tools consisting of entities interacting with each other. Indeed, we can rely solely on language to describe the production of, for example,

[41] Inoue and Matsuzawa, 2007.

[42] Kerney et al., 2017.

a hand-axe or spear. While tool use is not something unique to humans, we have seen only a few examples in the animal world. For example, some monkeys have learned to dry certain nuts, and then later use specific stones to crack them open—a skill that can take years to learn properly.[43] But monkeys are probably not able to create something as complex as a bow and arrow (see Chapter **??**).

Weapon evolution. Over time, our ancestors developed better and better weapons. For example, they added a sharp stone for additional weight, impact damage, and flight properties, and thus, invented the stone-tipped spear. Accurate ranged weaponry offered significant advantages to our ancestors. Not only did they become better at hunting, but also the prey's own defensive weaponry including hooves, claws, and fangs became useless against humans who were no longer within reach. Archaeological evidence puts spear use by our ancestors at as early as 500,000 BC.[44] This led to prey animals becoming more cautious. Individual animals that were more anxious had an evolutionary advantage over more courageous or curious animals. Thus, with each generation, they tried to stay farther away from anything that resembled a human. This put evolutionary pressure on humans to produce better and better tools, throw farther, and invent increasingly intricate hunting techniques and strategies. This created a predator-prey dependency. Like the evolution of the eye, improvements in our ability to make and throw projectiles brought us an advantage at every step of the way.

Self-domestication. Chimpanzees are much more aggressive than humans, but they are also more hesitant to go into a fight, given that it comes with a significant risk of injury. Humans, on the other hand, evolved the ability to attack from a distance, attack together with others, and even to plan an attack in advance. This put anyone at risk, no matter his or her status. Anyone could be challenged as long as there was support from other members of the tribe. This led

[43] Luncz et al., 2017.
[44] Wilkins and Chazan, 2012.

to significant changes within tribes of humans: the most aggressive or anti-social members of the tribe could be singled out more easily. Just like we domesticated wolves by selecting the least aggressive pups from a litter, humans self-domesticated by removing the most aggressive members of their tribe. While (for the most part) peaceful *within* the tribe, humans became efficient hunters for everything outside of their tribe. We still have to grapple with this dual nature of humanity—sharing a strong sense of community, while also expressing an "us versus them" mentality. On the one hand, we can easily make peace with the people around us; on the other hand, we can *rationalize* (by mentally degrading them) killing animals and killing humans from other tribes. While we might look down at chimpanzees for their in-the-moment aggression and impulsivity and see ourselves as the pinnacle of evolution, we also have to remember how easily humans can suppress their empathy once they have judged someone as "sub-human."

Interestingly, studies have shown that in mammals, certain genes regulate both aggressivity and aspects of anatomical features of the face. This genetic connection explains why we have shorter faces and smaller teeth compared to our primate cousins. Similarly, many domesticated dogs look less threatening than wolves. If our ancestors did not specifically breed wolves, it is conceivable that the least aggressive (and thus also least aggressive-looking) wolves were able to approach a human camp without being attacked by humans. A connection between behavior and facial structures can also be seen in humans. People who are missing a copy of the BAZ1B gene have the *Williams-Beuren syndrome* and are more talkative, outgoing, and less aggressive. They also have rounder faces with shorter noses, full cheeks, and wide mouths with full lips. Vice versa, people with additional copies of the BAZ1B gene (the *7q11.23 duplication syndrome*) tend to be aggressive, have difficulties socializing, and their facial features are also affected.[45]

[45] Zanella et al., 2019.

Rules and laws. Over time, human civilization has replaced the lethal way we deal with aggressive members of our tribes with methods of coping with our emotions: culture, customs, rules, and ultimately, laws. Those of our ancestors who were able to reflect upon their own status and position within society, and how it might feel to be another member of society, ultimately prevailed. As the anthropologist Richard Wrangham put it, "Those who followed the rules were favored by evolution."[46]

Compared to our primate cousins, humans are actually *much less* eager to change the pattern of how they carry out a task.[47] In a study, the participants—humans, rhesus macaques, and capuchin monkeys—had to select three icons in sequence to score a point (or get a banana) in a set of 96 trials. The third symbol showed up once the first two were selected in the correct order. In the second set of the trials, the third symbol showed up immediately; participants could either select all three symbols in order or select only the third symbol to get the reward directly. Most monkeys switched to the more efficient strategy of selecting the third symbol without delay, while humans tended to stay with their previous strategy. Preference for the familiar over a new approach was also confirmed in a second study comparing humans with chimpanzees.[48]

Protected childhood. Compared to babies of other mammals, human babies are totally dependent on their parents. This becomes obvious when comparing human babies to chimpanzee babies: without their mother, human babies are helpless, while chimpanzee babies are at least able to follow or hold onto their mother from early on. Intelligence-wise, human children catch up with chimpanzee children only at the age of one or two years. This is because the brain of a human baby continues to proliferate after birth; by contrast, in terms of growth, chimpanzee brains level off very soon after

[46] Wrangham and Grolle, 2019, cf.
[47] Watzek, Pope, and Brosnan, 2019.
[48] Pope et al., 2020.

birth. We should not look at prolonged childhood being an evolutionary mishap or obstacle, though. Instead, it is more a testament to the success of human parents to provide the necessary protection and nutrition during the earliest periods of their children's lives. It is an expression of the long-term *investment* into the brain development of the child.

Giving a baby the safe space to develop his or her brain without the need to survive independently gives humans an evolutionary edge. It is easier for the brain to put down new neural pathways in a part of the brain that is not being used at the time, just like it is easier for a construction company to replace rail tracks when no trains are using them. We have to keep in mind that we cannot just shut down our brain for a few days for architectural changes. While some cleanup processes happen during our sleep, we still have to be ready to respond within seconds when being awakened by, for example, the sound of a possibly dangerous animal or another human. The requirement to care for our children seems to be another evolutionary factor driving our longevity. As grandparents, we can spend resources on caring for our grandchildren or other relatives. This is not exclusive to humans; it has been shown that among killer whales, post-menopausal whales provided significant survival benefits for their grand-offspring.[49]

With our evolutionary history in mind, let us now take a closer look at the most complex part of our brain, the *neocortex*. In Chapter 1.5, we will look at how the brain processes sense data, while in Chapter **??**, we will cover how the brain initiates and executes movements. Taking everything together, we will examine how the brain can recognize itself in the mirror in Chapter **??**. Once we understand the brain parts involved in the input of sense data and output of motor actions, we can then proceed in Chapter **??** with the central topic of this book, consciousness.

[49]Nattrass et al., 2019.

1.5 A Glimpse into the Brain

How does the brain perceive its environment?

To grasp the brain's underlying functionality, it is best to look at how information flows through individual parts of the brain. While we have already discussed some aspects of the visual cortex, let us revisit it in more detail to see how different systems in the brain interact.

> **LOBE** · A *lobe* is an anatomical division or extension of an organ.

> **OCCIPITAL LOBE** · The *occipital lobe* is part of the *neocortex* and contains the *visual cortex* which is responsible for processing visual sense data.

> **CEREBRAL HEMISPHERES** · The *cerebral hemispheres* consist of the *occipital lobe*, the *temporal lobe*, the *parietal lobe*, and the *frontal lobe.* The two hemispheres are joined by the *corpus callosum.*

Figure 1.11 shows the architecture of the visual system.

- **Right visual field:** Light from the right visual field hits the left sides of the retinas of each eye.
- **Left visual field:** Light from the left visual field hits the right sides of the retinas of each eye.
- **Left retina sides:** Sense data from both left retina sides are communicated through the optic chiasm and combined in the *visual cortex* of the left cerebral hemisphere of the *occipital lobe.*
- **Right retina sides:** Sense data from both right retina sides are combined in the visual cortex of the right cerebral hemisphere of the occipital lobe.

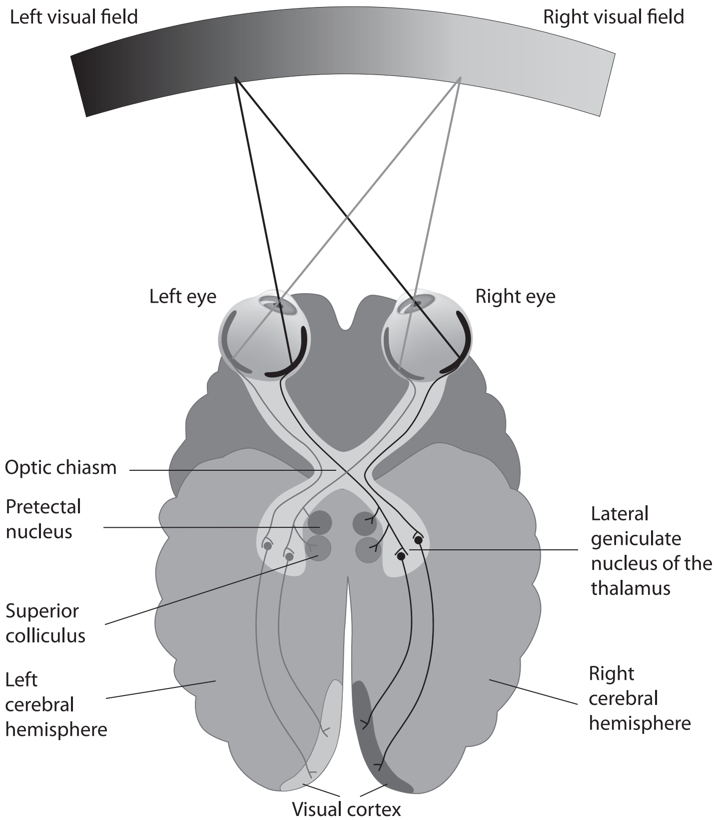

Figure 1.11: The basic visual projection pathway from our eyes to our neocortex. The eyes' lenses project light onto the retinas of each eye. There, light-sensitive cells translate light into electrical impulses. The left side of the projected image is sent to the right hemisphere, and the right side of the projected image is sent to the left hemisphere (image source: Shutterstock).

Ultimately, information from the right visual field is processed in the left visual cortex, and information from the left visual field is processed in the right visual cortex. Between the optic chiasm and the visual cortex, the signal passes through the left and right lateral geniculate nucleus. There, the sense data is pre-processed and transferred to various brain parts, with the visual cortex the most important one. Pre-processing means that the brain analyzes the images and modifies them for further processing by other brain parts.

There are a number of possible reasons evolution led to this rather convoluted architecture where the optic nerves of both eyes cross in the optic chiasm and split the information from the eyes' left and right visual fields. If the left eye were directly connected with the left visual cortex and the right eye directly connected to the right visual cortex, losing one eye would mean that one visual cortex would either no longer receive any input, or it would receive the input too late because it first had to be transferred from the other hemisphere. The crossing in the optic chiasm enables the visual system to work even in the case when only one eye functions properly.

1.5.1 Color Perception

To understand vision, we first need to understand color and light. Light rays are actually electromagnetic waves. Depending on the length of the waves, we experience them as different colors on the color spectrum (so-called spectral colors, see Figure 1.12). To perceive colors, our eyes have photoreceptor cells sensitive to red, green, and blue light (see Figure 1.13). In addition, shorter wavelengths activate both the red and blue photoreceptor cells, making them look purple.

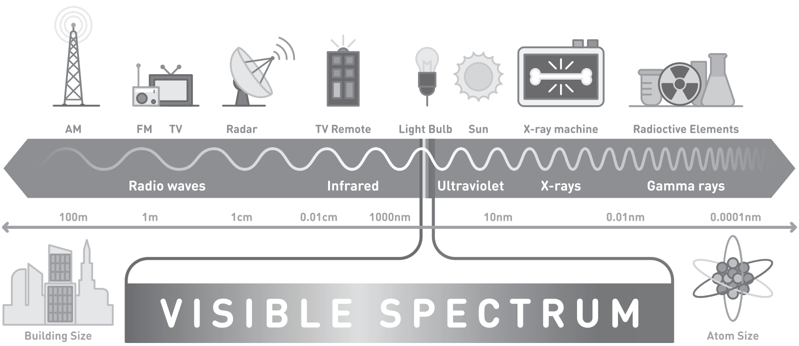

Figure 1.12: The electromagnetic spectrum (image source: Shutterstock).

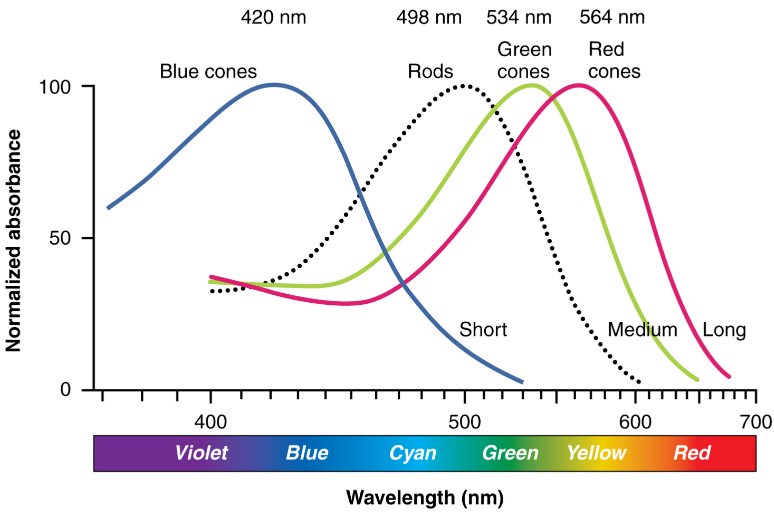

Figure 1.13: Sensitivity of the cones and rods differs depending on the wavelength (image source: Openstax, Rice University).

Now, imagine throwing a stone into a lake. Depending on the size of the stone, water waves of different size will emerge. A large stone will lead to long water wavelengths, a small stone will lead to short water wavelengths. If you threw multiple stones into the water, there would still be water waves, but they would overlap with each other. Just like no single stone can create such an overlapping of water waves, no single light source can create all the colors we can perceive. This is why beyond the colors on the electromagnetic spectrum, we also experience *extra-spectral colors* like white, gray, black, pink, or brown when different photoreceptor cells are activated in combination (see Figure 1.14). Those colors could be compared with multiple stones thrown into the water. For example, a pink flower reflects red light waves, but also reflects green and blue light waves. Similarly, white, gray, and black are the product of different wavelengths at the same intensity, and brown is simply orange at low light intensity.

Red	**Green**	**Blue**	**Interpretation**
100%	0%	0%	red
0%	100%	0%	green
0%	0%	100%	blue
100%	100%	100%	white
50%	50%	50%	gray
0%	0%	0%	black
100%	75%	80%	pink
100%	60%	0%	orange
75%	20%	0%	brown

Figure 1.14: A translation of the activated photoreceptor cells to the subjective experience of color.

That extra-spectral colors are a combination of different wavelengths of light was not discovered until Newton's famous prism experiment in 1666. Before that, it was thought that prisms *produce* colors, but it was Isaac Newton who showed that a prism merely *splits* light into its spectrum. By adding a second prism, Newton proved that the red light from the first prism produced only red light in the second prism, and that he could recombine different colors of light back into white light (see Figure 1.15). This experiment became a symbol for the Scientific Revolution because it replaced a subjective understanding of light with objective, observable facts. The existence of extra-spectral colors show that our subjective experience of the world is pre-processed. The LGN integrates the information from the retina into color information. For example, if we look at a purple van, our red and blue photoreceptor cells are activated. But no matter how close we get to the van, we never see separate blue or red color elements. What we see is pre-processed for us through the combination of different sources of sensory information into new data, the color purple.

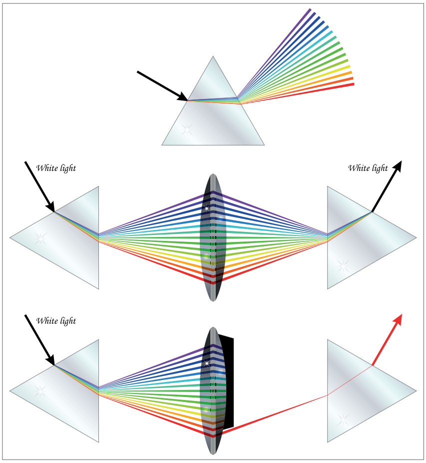

Figure 1.15: Newton's experiment that demonstrates how white light actually consists of light of different colors (image source: Shutterstock).

More complex processing involves the inclusion of the three-dimensional data the LGN has derived from sense data. It is used to further modify the way the LGN integrates color perception. Consider the checkers shadow illusion in Figure 1.16: while in the first picture it looks like a checkerboard with a three-dimensional black ball throwing its shade over the board, the second picture shows how both marked squares were printed (or are displayed) with the identical shade of grey. Our brain processes the image to give us the impression of how the checkerboard would look without the shadow. Without this processing, it would look like the shadow was actually printed on the checkerboard.

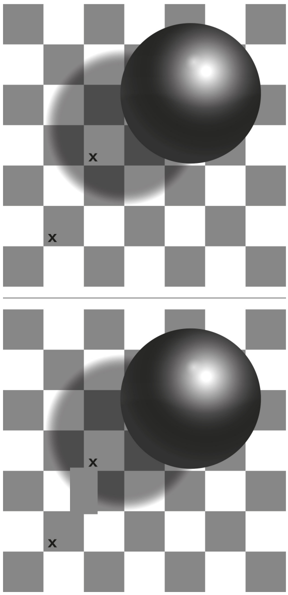

Figure 1.16: The checkers shadow illusion misleads the viewer into thinking that the two-dimensional image of a three-dimensional checkerboard is evenly colored black and white. The second image shows that the squares inside and outside the shadow are identical in color (image source: Shutterstock).

1.5.2 The Brain as a Prediction Machine

Processing visual and auditory data requires time. Studies have shown that the brain needs around 190ms for visual stimuli and 160ms for auditory stimuli.[50] This poses a significant problem: any decision the brain makes is calculated based on old information. A delay of 190ms does not sound like very much. But imagine a ball that is thrown at you with a speed of 100km per hour (or about 15 meters per second). In 190ms, the ball travels a distance of around five meters. With that delay, you would always catch the ball too late. This problem becomes even more complicated if you are moving. To deal with this delay, the brain tries to predict the positions of where objects will be in the near future based on their current speed. This helps other parts of the brain to make more accurate decisions, for example, catching the ball in the right moment.

There are a few instances where this prediction process of the brain fails noticeably. Consider the *Hering illusion* in Figure 1.17: the straight lines near the central point appear to curve outward. Our visual system tries to predict the way the underlying scene would look in the next instant if we were moving toward its center. The cost of predicting the future to reduce reaction times is that we sometimes experience this correction as an optical illusion.[51]

While we can establish that optical illusions are the product of preprocessing and ultimately useful for us, the question is *why* there is a difference between how we *experience* what we see and what is actually there. One could argue that it is just an optimization or filter by the brain for specialized applications (movement, 3D, faces, and so on). But this does not explain why this optimization feels *real* to us, even when we have evidence to the contrary.

[50] Welford, 1980.

[51] Changizi et al., 2008.

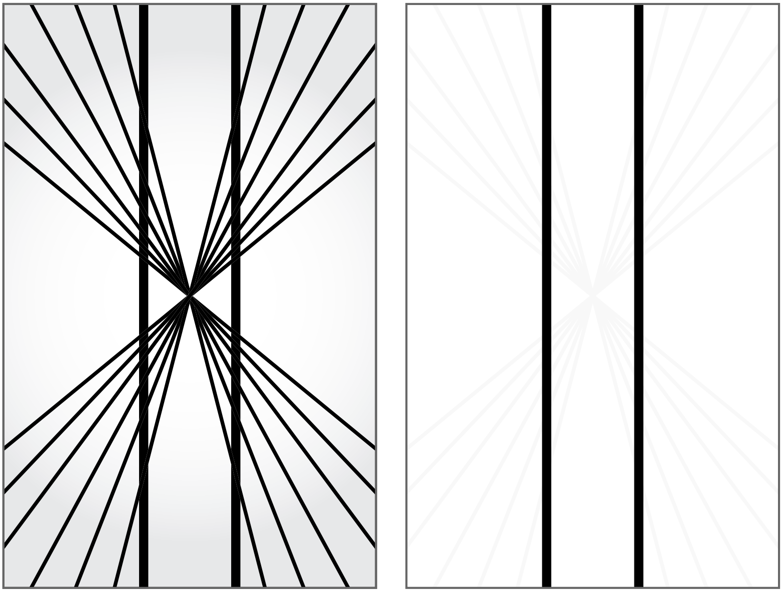

Figure 1.17: Two parallel lines look skewed when the mind is given a spatial context (image source: Shutterstock).

1.5.3 The Ventral and Dorsal Streams

The output from the visual cortex continues as two separate data streams:

- The ventral (lower) stream (the *what*) through the temporal lobe (see Figure 1.18).; and
- The dorsal (upper) stream (the *where* and *how*) through the parietal lobe.

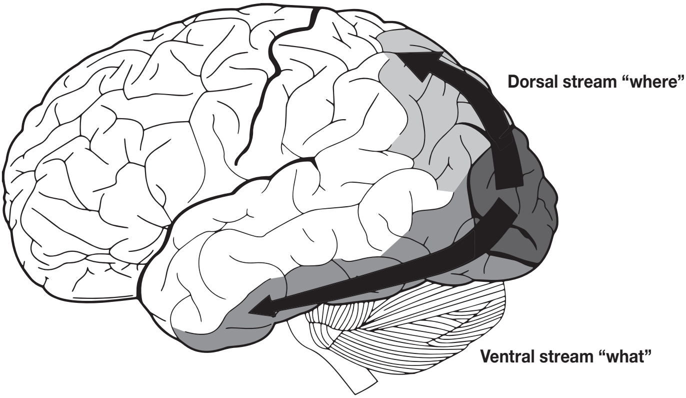

Figure 1.18: Image showing the ventral stream (the *what*, at the bottom through the temporal lobe) and the dorsal stream (the *where* and *how*, at the top through the parietal lobe) in the human brain visual system (image source: Selket, Wikimedia).

The *temporal lobe* processes visual information to categorize *what* things are, while the *parietal lobe* integrates the spatial information into a map of *where* and *how* things are. For example, looking at an apple on a table, the temporal lobe identifies that there is an apple and a table, and the parietal lobe identifies that the apple is on top of the table.

> **Temporal lobe** · The *temporal lobe* is the part of the neocortex that deals with the "what": long-term memory, and object, face, and speech recognition.

> **Parietal lobe** · The *parietal lobe* is the part of the neocortex that deals with the "where," especially the location of entities, the "how," as well as touch perception.

Compared to the dorsal stream, the ventral stream is processed more quickly. It is more important to know what you see (a tiger, a fire, an acquaintance, etc.) than where it is. This idea of prioritization of the processing of the sense data can also be found in the general architecture of the visual system.

One could ask why our visual cortex is at the very back of our brain given that it takes valuable time for a signal to pass through the brain. Why not have all visual processing at the front or at least directly behind the eyes? Given the actual architecture, processing in the visual cortex seems to have a low priority. It is furthest away from the eyes—the opposite of what we would expect from an organ that can require an immediate response.

Looking at it from an engineering point of view and turning the question around, we would ask: what essential functions of the visual system should be put at the front? That is, reflexes to close your eyelids to protect your eyes, to combine information from your left and right eye, to turn your head to a source of movement or sound, to focus your lenses, and to constrict your pupils to protect your retina. All brain parts responsible for these abilities are positioned around the superior colliculi near the eyes. They provide us with reflexes and mechanisms to protect the eyes and refocus them.

After the initial processing in the superior colliculi, the processing goes through the LGN. There, a three-dimensional representation of the world is created, with just enough detail to allow for quick —possibly life-saving—reactions. For example, in a ball game, if we always had to first conceptualize that a ball is flying at us and plan for its arrival, our reactions would be very slow. Learning to catch a ball requires us to bypass conceptualization and just "do"—trusting our instincts supported by early calculations in the LGN before the information even reaches our visual cortex.

1.5.4 The Temporal Lobes

The temporal lobes of the cerebrum are positioned on the left and right side of the brain, near the ears. They process auditory signals and are responsible for identifying *what* is being said (or seen, as part of the ventral stream). Not only does this brain part identify what you see, but it also maps it to language (in *Wernicke's area* of the left temporal lobe). If Wernicke's area is damaged, you would use *individual* words correctly, but in combination, the words may not make any sense.

> **WERNICKE'S AREA** · *Wernicke's area* is located in the left side of the temporal lobe. Its function is the *comprehension* of speech. Damage to Wernicke's area leads to people losing the ability to form meaningful sentences. It is connected to Broca's area, which is responsible for muscle activation to *produce* speech.

The brain part in the right hemisphere corresponding (homologous) to Wernicke's area deals with subordinate meanings of ambiguous words (for example, "bank" refers to a financial institution but could also refer to a river bank).[52] With the ventral stream, you can identify that you are seeing a tree and connect it to the abstract concept of a tree. It also allows you to map the concept of a tree to the image of a tree or to the sound of the word "tree." This mapping is ultimately connected to a past experience. In terms of learning languages, we connect a word with the experiences we had when hearing or reading the word in the past. Someone pointed to a tree, said "tree," and we connected sound and image with the concept of a tree. As this suggests, the temporal lobe is essential to processing memories. This is supported by the fact that the temporal lobe is also connected to the hippocampus, providing spatial memory and short-term memory, as well as helping to create long-term memories.

[52] Harpaz, Levkovitz, and Lavidor, 2009.

Figure 1.19: A basic drawing of a kitchen. Despite most of the visual information (textures, colors) being stripped from the image, we can immediately classify it correctly (image source: Shutterstock).

One could argue that a comic strip is the brain's internal representation of what is left after the brain has processed an image—just like the word "tree" is a representation of a real tree. To conceptualize the environment, the brain tries to strip all superfluous information from an image.[53] For example, Figure 1.19 shows a simplified drawing of a kitchen. We can immediately recognize it as a kitchen. Abstract symbols that are stripped of all superfluous information (colors, textures, etc.) are even *easier* (especially with less ambiguity) to recognize, hence their use in street signs.

[53] Morgan, Petro, and Muckli, 2019.

1.5.5 Facial Recognition

Given that we can remember thousands of faces despite them differing only minimally, it is no surprise that we have specialized mental machinery specifically for faces or face-like structures. The temporal lobe contains the *fusiform face area* that deals only with identifying faces. People who lack this ability of the brain to pre-process faces have prosopagnosia ("face-blindness"). Imagine that everyone you meet is wearing a mask: you would have to remember what clothes someone usually wore, how her voice sounded, and categorize people by their hairstyle, height, or body type. Similarly, if we have not encountered enough people from a particular background (Asian, African, European) to have learned to distinguish her facial features, we might have difficulties recognizing individual differences.

Our face recognition is so important that it goes as far as seeing faces where there are none. For example, a standard American power outlet is just that, a power outlet (see Figure 1.20). We are "projecting" that it is a surprised face, although we are absolutely sure that there is certainly not a (human) face in the wall. It seems that we share this ability to recognize basic facial features (two circles and a mouth) at least with reptiles, going back more than 300 million years in our evolutionary history.[54] Looking for faces everywhere can help us to quickly recognize a friend (or enemy)—at the low cost of identifying faces when there are none.

[54] Versace, Damini, and Stancher, 2020.

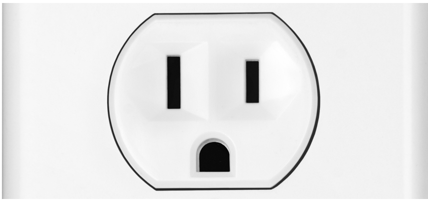

Figure 1.20: A standard American power outlet, which looks like a surprised face (image source: Shutterstock).

The downside of this pre-processing is that we can have a harder time focusing on details of a (known) face. The "Thatcher effect" is a demonstration of this. Looking at Figure 1.21, you can see a young woman's face with a neutral expression. But turn this book upside down, and you will see a woman with a creepy grimace. This is because your ability to recognize faces is optimized to recognize people standing on their feet rather than hanging upside down from a tree. For the neural networks our brain uses, it would take extra effort to check whether or not mouths and eyes are oriented in the right direction. People with prosopagnosia are affected by the Thatcher effect, too, as their only struggle is with the classification of the face as a whole. They still use the same machinery as people without prosopagnosia to classify individual facial features (like the eyes or mouth). It is like the opposite of not being able to see the forest for the trees: we get the meaning of something ("this is a face of a young woman") but miss the details ("her eyes are upside down").

The *extrastriate body area* and the *fusiform body area* are similar to the fusiform face area. They are located in the visual cortex near the fusiform face area and deal with recognizing body parts and body shapes, and analyzing the relationship of moving limbs. Weaker connection between the extrastriate body area and the fusiform body area can lead to misjudgements of one's own body size and to illnesses like anorexia nervosa.[55]

[55] Suchan et al., 2013.

Figure 1.21: Turn your book upside down to experience the "Thatcher Effect." It demonstrates how our visual system is optimized to recognize people standing on their feet rather than hanging upside down (image source: Shutterstock).

1.5.6 Delusions

Faces are evaluated not just in the temporal lobe but also in the amygdala. If the fusiform face area was not working properly, we would still experience an emotion but would not recognize the face. If there is a problem with the connection between the thalamus and the amygdala, we might recognize a face but would lack the emotional response to the face (see Figure 1.22). This can lead to a *monothematic delusion*, namely the *Capgras delusion*.[56]

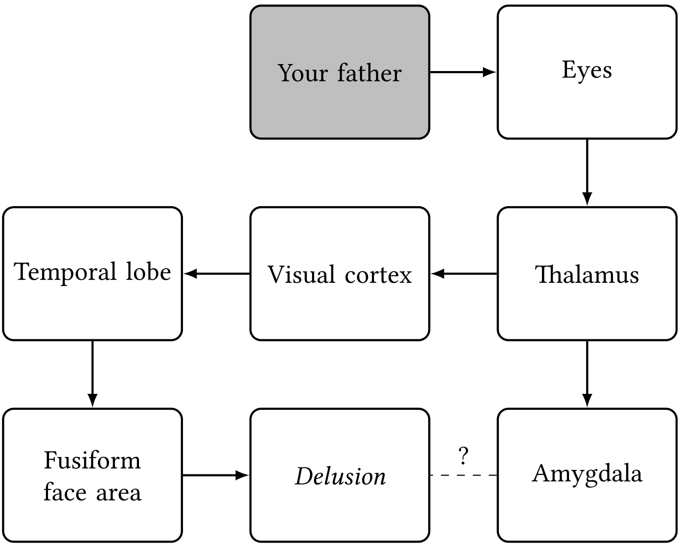

Figure 1.22: If your amygdala does not provide the right emotional information related to a perception, the conflict with the information from the fusiform face area can lead to experiencing the Capgras delusion (in which you assume that the person is an imposter).

[56] Ramachandran, 1998.

> **Monothematic delusion** · A *monothematic delusion* is a delusion focused on a single topic. A delusion is a firm belief that cannot be swayed by rational arguments. It is distinct from false beliefs that are based on false or incomplete information, erroneous logical conclusions, or perceptual problems.

> **Capgras delusion** · A person suffering from *Capgras delusion* can recognize people who are close to him, but he thinks they have been replaced by clones or doppelgangers. One cause for this condition is a damaged or missing connection from the amygdala that leads to a person having no emotional connection to those whom he sees.

The Capgras delusion is the belief that a person emotionally close to you (for example, your father) has been replaced by an imposter. You definitely see that the person is exactly as you have him in your memory; it is just that you no longer feel an emotional connection to him. For the brain, the most apparent (although weird) solution to solve this conflict is to assume that someone is impersonating your loved one. You cannot give clear reasoning for it, but based on the facts (the sense data identifying the person plus the lack of an emotional connection), it is the most logical conclusion. This can also happen in healthy people with movie actors. Having built an emotional connection to the character a person plays, there is a disconnect when meeting the actor in person: the actor looks exactly like the character but the emotional connection to the actor is missing. The best explanation the brain might come up with is that the person whom you are seeing (and who is the actor) is an imposter. This is more probable when meeting the actor outside the usual environment (convention, conferences, movie award events, etc.) in daily life (at the grocery store).

Other noteworthy delusions are:

- Fregoli delusion (all the people you meet are actually the same person in disguise);

- Syndrome of subjective doubles (there is a doppelganger of yourself acting in your name);
- Cotard delusion (you are dead or do not exist);
- Mirrored-self misidentification (the person in the mirror is someone else); and
- Reduplicative paramnesia (a place or object has been duplicated, like the belief that the hospital to which a person was admitted is a replica of an actual hospital somewhere else).

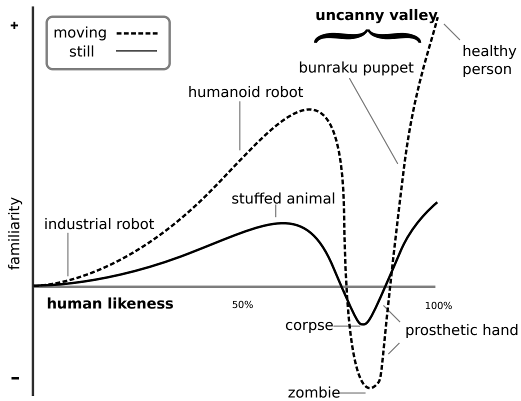

Figure 1.23: The "uncanny valley" effect with human-like dolls or robots (image source: Karl MacDorman).

Somewhat related to delusions is the "uncanny valley effect."[57] We have no problem dealing with dolls. However, when they become too human-like (but not fully human-like), we experience feelings of eeriness and revulsion (see Figure 1.23). This is why zombies (and to an extent, human-like robots) are used in horror movies. Even modern computer graphics artists have serious problems creating believable faces. We can notice the smallest deviation from reality even if the face geometry fully matches the human face. The artist has

[57] Rosenthal-von der Putten et al., 2019.

to hit all the marks when it comes to lighting, mouth movements, nose shadows, skin pore structure, and so on. This is of no surprise as research points to face recognition being highly evolved as it is used also to detect kinship[58] which is an evolutionary advantage in taking care of relatives as well as for mate selection.

> **Uncanny valley effect** · The *uncanny valley effect* refers to the negative reaction to dolls or robots that are very (but not fully) human-like. Possible reasons for this reaction are an inbuilt instinct to avoid corpses, and the inner conflict and discomfort of switching back and forth between seeing a being as fully human or a lifeless object.

The uncanny valley effect is similar to the Capgras delusion in regard to there being two pieces of conflicting information in the brain. One pathway tells you "This is a human!" while another warns "No, that is no human," and the brain has to sort it out somehow, leaving you with a strange feeling of uncertainty. Some of us might have experienced the sudden shock at night when we see a person standing in our living room, only to discover that it is just the clothes rack. The physical presence of a person implies relationships, conflicts, alliances, and enemies. Humans can be more dangerous than the wildest animal, hence anything that resembles a human gets the most immediate attention. In addition, some of the discomfort could also stem from pathogen avoidance (a nearly human-like robot could also be seen as a real human with a serious illness or even as a corpse).[59]

With perception on the one side, we now need to look at consciousness from the other side: action. To act in this world, we need to know that we have a body and know how to use it. We need to differentiate between self and other by creating a so-called "body schema" which we will discuss in Chapter **??**.

[58] Kaminski et al., 2009.

[59] Moosa and Ud-Dean, 2010.

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> What I cannot create, I do not understand.
>
> —Richard Feynman

Glossary

A

Aggregate • An *aggregate* is a number of entities that have a reciprocal effect on one another, so that they can be considered collectively as their own entity (e.g., a cup full of water—all water molecules interact with each other).

Allocortex • The *allocortex* is part of the cerebral cortex (the *neocortex* is the other part) and consists of the olfactory system and the hippocampus.

Amygdala • The *amygdala* is the brain's value and emotion center. It helps with evaluating thought patterns of the basal ganglia depending on the context instead of the mere strength of the signal. It also connects the brain with the hippothalamus, providing a bridge to the hormonal system.

Angular gyrus • The *angular gyrus* combines visual, auditory, and somatosensory information and puts things into relationship with each other. The *left angular gyrus* deals with relationships in the external world, especially relating to words and letters, and the *right angular gyrus* deals with the relationship between the self and the external world.

Attention • *Attention* is the brain's process of limiting alternative thought patterns, then increasing the most dominant thought pattern's strength. It is like a simple majority rule: the most successful thought pattern gets all the resources while other thought patterns are suppressed. While we can jump back and forth between different thoughts, we cannot have two dominant thought patterns at the same time.

Attention schema • The *attention schema* is a model the brain creates of the process of attention. It allows access to the working memory in order to be able to intervene before an action is taken.

Awareness • *Awareness* is a description of the process of attention. Something can grab the attention of your brain, but to talk about it, you need a model of what is happening in your brain. Awareness is such a model.

Awareness schema • The *awareness schema* is a model the brain creates of the process of awareness. With the awareness schema, the brain can write to the working memory to influence what the brain will focus on next. It also allows the brain to imagine alternative, past, or future scenarios.

B

Basal ganglia • The *basal ganglia* are a part of the brain that, like a referee, arbitrate decisions by the neural committees. Also, like an orchestra conductor, they coordinate the sequence of entire motor programs. In both cases, they do not make decisions but merely provide rules and structure.

Blindsight • Someone suffering from *blindsight* reports that he cannot see. However, experiments show that he can react to visual cues. As a result of damage in the visual cortex, information from the retina arrives in the midbrain but does not undergo conscious processing through the visual cortex.

Body schema • The *body schema* is the brain's simplified description of the status of the body. It is built by correlating what we see and feel our body is doing with signals that the brain sends to the muscles.

Broca's area • *Broca's area* is a brain part located in the left side of the frontal lobe and connected to Wernicke's area. It is responsible for the *production* of speech. Damage to Broca's area leads to a person unable to find the words to express what he wants to say. The homologous area in the right hemisphere deals with non-verbal communication.

Buddhism • *Buddhists* (Buddha lived 563–483 BC or 480–400 BC depending on the source) believe in a difference between brain and consciousness, with consciousness being compared to a light that shines on thoughts. The mind dies with the bodily death while "you" are reborn into a new being with no memories of your previous life.

C

Capgras delusion • A person suffering from *Capgras delusion* can recognize people who are close to him, but he thinks they have been replaced by clones or doppelgangers. One cause for this condition is a damaged or missing connection from the amygdala that leads to a person having no emotional connection to those whom he sees.

Cartesian theater • The *Cartesian theater* is a term coined by Daniel Dennett to criticize most of the contemporary explanations of consciousness. At their core, such explanations all share the view that there is some sort of miniature person ("homunculus") or entity within the brain looking at what we are looking at—an idea which ends in an infinite series of subsequently ever-smaller Cartesian theaters with ever-smaller homunculi.

Category • A *category* is the mental correlation between entities.

Causality • *Causality* refers to the effect of one or several entities on another entity in a certain situation (e.g., an accident is no random occurrence, there are one or several causes which led to the accident, such as lack of sleep, a technical defect, poor visibility, etc.).

Cause • A *cause* refers to the entity that has or had an effect on another entity (e.g., the ice cube in the glass is the cause for the drink having gotten or stayed cold).

Cerebellum • The *cerebellum* is the brain part that helps with coordination of complex behavior. It provides a set of motor programs the brain can choose from repeatedly for similar actions (even in time-critical situations). With the help of the cerebellum we can, for example, walk or bicycle without having to consciously think of each movement.

Cerebral cortex • The *cerebral cortex* is the outer layer of the cerebrum. It contains most of the neurons of the brain.

Cerebral hemispheres • The *cerebral hemispheres* consist of the *occipital lobe*, the *temporal lobe*, the *parietal lobe*, and the *frontal lobe.* The two hemispheres are joined by the *corpus callosum.*

Cerebrum • The *cerebrum* includes the neocortex (the cerebral hemispheres), and the allocortex (the hippocampus, the basal ganglia, and the olfactory bulb).

Concept • A *concept* is a category that is delineated by a definition, and determined by the nature of the entity.

Concept hierarchy • A *concept hierarchy* is a tree-like structure consisting of concepts, defined by the definitions of given connections (e.g., "chair" and "table" are furniture, the concept "furniture" would thus constitute the root of a tree and "chair" and "table" are two successive branches).

Configuration of a property • The *configuration of a property* relates to the intensity of a certain property of an entity.

Consciousness • *Consciousness* is an umbrella term for the brain's abilities to process sense data, focus on something, be aware of something, have the ability to process high-level information (attention schema), be able to control awareness (awareness schema), and reflect on abstract information (philosophy and science).

Contradiction • A *contradiction* can result from a (possibly erroneous) logical integration. This becomes visible when the corresponding concept has a property while *not having* it at the same time (such as an invisible pink unicorn, boiling ice, a full empty cup, etc.).

Copenhagen interpretation • In the *Copenhagen interpretation* of quantum mechanics, an observer is required for the wave function to collapse. Without observation, the wave function never collapses and never becomes a particle. While the interpretation does not mention consciousness as such (measurements by a device are observations, too), it raises the question of who observes the observer, resulting in an infinite loop.

Corpus callosum • The *corpus callosum* connects the left and right brain hemispheres, coordinating tasks requiring both sides.

D

Declarative memory • *Declarative memory* connects one memory with another. For example, the amygdala maps thalamic sense input to emotions; the hippocampus maps places with each other for orientation; and the neocortex maps concepts with other concepts (a tree is a plant).

Deduction • With *deduction*, we conclude from the general case the special case. For this, we use the knowledge that we gained from induction, check if a certain perception fits the definition of a concept, and conclude for the corresponding entity that it has all the properties of the corresponding concept. In short, deduction is the process of subsuming new instances under a known concept (cf. Rand, Binswanger, and Peikoff, 1990, p. 28). Deduction thus operates in the opposite direction as induction. For example, if we notice that cars can drive on the street, and we see a parked car, then we can deduct that this car is able to drive on the street as well, because we have assigned the parked car to the known concept "car."

Definition • A *definition* is the possible demarcation of a number of entities by means of perceptions, concepts, and axioms (e.g., grass is a "plant," a "living organism" which uses "photosynthesis.") It consists of a list of properties and processes of entities (cf. Rand, Binswanger, and Peikoff, 1990, pp. 71–74) in question.

E

Effect • An *effect* is the change caused to the configuration of the properties of an entity (e.g., the heating of water changes its temperature).

Emergent property • An *emergent property* is a property of a system that emerges only when its parts are combined or interact with each other. Individual parts of that system do not have the emergent property themselves. For example, the division of labor in ant colonies allows the ants to be more efficient than if individual ants fended for themselves.

Encephalization quotient • The *encephalization quotient* (EQ) is a measure of relative brain size and is often used to convey how small or large a species' brain is compared to that of other species of similar body size.

Entity • An *entity* is a "thing" with properties (an identity). For example, a plant produces oxygen, a stone has a hard surface, etc.).

Episodic buffer • The *episodic buffer* is responsible for remembering the sequence of events, including the last state of an entity.

Evil demon • Descartes' *evil demon* is a thought experiment to differentiate the immaterial mind from the brain. His "evil demon" is an entity that could make any changes to the material world without anyone being aware of such changes. Descartes' assumption was that by examining the remaining things we could rely on, we would discover what the immaterial mind is.

Evolution • *Evolution* is the combination of the process of selection together with a system of cloning or procreation.

Exaptation • *Exaptation* is the use of a certain trait for a problem or environment other than what it was originally "intended" for. An example would be feathers that started out as heat insulation, and only later were used to improve jumping, and finally for flight.

Executive functions • The *executive functions* represent a series of means by which the prefrontal cortex can suppress thought patterns in other parts of the brain. While winners in the neural competition are selected with the help of the basal ganglia, the prefrontal cortex can counteract those decisions in favor of other actions. The prefrontal cortex makes these decisions based on its models. For example, stealing goes against the norms of society, so the prefrontal cortex suppresses the (utilization behavior of the parietal lobe's) urge to grab someone else's property.

F

Fitness landscape • The *fitness landscape* is the sum of all environmental influences on an entity. For example, if you are sifting sand, a riddle screen lets small particles of sand fall through while larger stones are retained. In this case, the riddle screen and the shaking of the riddle screen would be the "fitness landscape." In nature, the fitness landscape would simply be the environment over time, including all other life forms, the climate, etc.

Frontal lobe • The *frontal lobe* of the neocortex deals with running a simplified simulation of the world. It provides us the ability to plan and evaluate actions and their future impact. The somatosensory area of the parietal lobe is directly adjacent to the frontal lobe.

G

Generation • A *generation* is a set of systems during one cycle of procreation.

Genotype • The *genotype* is a system that is the blueprint for the phenotype.

Gyrus • A *gyrus* is a fold or ridge in the cerebral cortex.

H

Hard problem of consciousness • The *hard problem of consciousness* asks the question where the subjective experience of consciousness comes from. It is "hard" as there are no known ways of detecting this experience objectively without relying on the subjective claims of an individual (or ourselves).

Hemispatial neglect • Someone suffering from *hemispatial neglect* lacks consciousness of half of his visual field. The person is not aware that his vision is impaired in any way, making the condition different from blindness in one eye. People with this condition have to learn abstract strategies as a way of coping.

Hierarchy tree (of concepts) • A *hierarchy tree of concepts* refers to the directional ordering of concepts according to their inheritance.

Hippocampus • The brain's *hippocampus* provides us with a mental map for navigation. It also builds temporal relationships between places, allowing us to determine, for example, which areas in our environment we have already foraged and in which areas the plants have regrown. The *hippocampus* and the *olfactory system* (sense of smell) make up the *allocortex*.

Homunculus argument fallacy • The *homunculus argument* is the fallacy of trying to explain consciousness by another (smaller) conscious person (the "homunculus") observing and steering you. The problem with this explanation is that it remains unexplained how this smaller homunculus subsequently experiences consciousness.

I

Identity • An *identity* is the sum total of all properties of an entity (e.g., weight: 160 pounds, length: 6 feet, has a consciousness, etc.).

Indian idealism (Vedanta) • In the *Indian idealist* worldview, there is but a single consciousness and our experience of the world as separate beings or consciousnesses is an illusion.

Induction • With *induction*, we conclude from the special case (a number of concrete perceptions) the general case (the concept). With this, we create new or refine existing concepts, on the basis of sense data and the logical integration of a number of perceptions of entities. For example, if we see a number of cars with different colors, we create from this observation the more general concept "car" by using induction.

Inheritance (of a concept) • A concept with an *inheritance of another concept* builds upon the other concept's definition. If the concept "table" inherits from the concept "matter," the former would build upon the property "mass" of the latter.

Integration • *Integration* is the classification of perceived entities into one or several concepts, as well as classification of existing concepts into more general concepts or a concept hierarchy (e.g., the classification of a perceived sound wave as a definite word, or classification of the concept "human" into the more general concept "life-form").

Intuition • Your initial evaluation of a situation is called *intuition.* It is the first thing that comes to your mind without going through conscious deliberation or reasoning.

K

Knowledge • *Knowledge* constitutes sense data, logically integrated perceptions, concepts, or concept hierarchies. It can also be created from logically integrated conclusions from existing knowledge.

L

Lateral geniculate nucleus • The *lateral geniculate nucleus* (LGN) is part of the thalamus and relays information from the retinas (via the optic chiasm) to the visual cortex. It pre-processes some of the information, for example, combining red, green, and blue photoreceptor cells into colors.

Lobe • A *lobe* is an anatomical division or extension of an organ.

Logic • *Logic* is the method of non-contradictory integration of knowledge or perceptions.

Loop of consciousness • The *loop of consciousness* refers to a network of connections in the brain from the thalamus to the cortex, then to the basal ganglia, and then back to the thalamus (also called the *cortico-basal ganglia-thalamo-cortical loop*). It is believed that this is the source of our subjective experience of the world.

M

Many-minds interpretation • The *many-minds interpretation* of quantum mechanics is similar to the many-worlds interpretation, in which the universe splits into infinite universes. In the many-minds interpretation, the split of the universe happens with each thought for each individual brain, instead of with each measurement (as in the many-worlds interpretation). Consequently, one's consciousness splits into many consciousnesses whenever a decision was made.

Materialism • In the *materialist* worldview, there is no separate "mind." Instead, everything can be explained by a single substance (matter).

Mechanistic theory • A *mechanistic theory* is a theory that explains a system as if it were a computer program or a mechanical machine with gearwheels: you can understand it by tracing the input to the output. Pedagogically, a mechanistic theory is of great value as we can explain the essential workings of a system step by step using a diagram with boxes and arrows.

Mind-brain dualism • The philosophical view of *mind-brain dualism* (or also *mind-body dualism* with "body" including our brain) states that what we call the (immaterial) mind is separate from the material world (the body, including the brain).

Mirror test • The *mirror test* evaluates the ability of an animal to recognize itself in a mirror after a researcher has secretly added a blot of coloring to the animal's body and put the animal in front of a mirror. If the animal starts investigating the blot of color on its own body instead of on the mirror image, it passes the test (because that indicates the animal realizes it is the same creature that it sees in the mirror).

Model • The *model* of an entity is a simplified simulation of that entity. It consists of the entity's concepts and its properties, as well as some of the entity's measurements.

Monism • The philosophical view of *Monism* is that everything that exists (including what we call mind or consciousness) can be traced back to a single fabric of the universe. The consequence of this view is that the mind must be a result of a (mechanistic materialist) process and that mind and matter are not two separate things.

Monothematic delusion • A *monothematic delusion* is a delusion focused on a single topic. A delusion is a firm belief that cannot be swayed by rational arguments. It is distinct from false beliefs that are based on false or incomplete information, erroneous logical conclusions, or perceptual problems.

Mutation • A *mutation* is a change of the genotype of a life form. This change can, but does not necessarily, have consequences for the phenotype.

N

Neocortex • The *neocortex* is the newest part of the mammalian brain and consists of the *cerebral hemispheres.* Its main tasks are focus, language, long-term planning, and modelling of the world. It can generate strategies that involve detours if goal-directed behavior is not successful (for example, going around a fence instead of trying to get through it).

Nerve net • A *nerve net* is nervous system without a central organization. This means that any signal (that exceeds a certain signal strength) the nerve net receives through its senses causes a singular reaction. Hydras have this kind of nervous system and use it to contract their body when prey touches their tentacles.

Neutral monism • In the *neutral monist* worldview, while both mind and matter exist, they both stem from a third, undefined substance.

Nocturnal bottleneck hypothesis • The *nocturnal bottleneck hypothesis* posits that many mammalian traits were adaptions to moving into a niche to become nocturnal animals and evade the dominant dinosaurs.

O

Object permanence • The ability of *object permanence* allows us to track predicted positions or movements of objects even after they have vanished from our field of view. By running a simplified simulation of the world, we are aware that a tiger that has jumped behind a tree is still there.

Objectivism • *Objectivism* (founded by Ayn Rand, 1902–1982) is a monist philosophy that recognizes a distinction between the brain and a "prime mover" that has a power of whether to focus the brain or not.

Occipital lobe • The *occipital lobe* is part of the *neocortex* and contains the *visual cortex* which is responsible for processing visual sense data.

P

Parietal lobe • The *parietal lobe* is the part of the neocortex that deals with the "where," especially the location of entities, the "how," as well as touch perception.

Phenotype • The *phenotype* is the actual body of a life form. Changes in the phenotype generally do not have effects on the genotype. Generally only the phenotype interacts directly with the environment.

Philosophical zombie • A *philosophical zombie* is a hypothetical being that acts exactly like a human but lacks the inner conscious experience. The existence of a philosophical zombie is used as an argument against consciousness being a mechanistic process: if we are but a mechanistic machine, why would we need a subjective, conscious experience? This argument is addressed by pointing out the necessary evolutionary advantage of having a conscious experience, which is the ability to focus and to explain oneself to others.

Phonological loop • The *phonological loop* is an acoustic memory system of the brain that holds spoken words or sounds. It involves (among other brain parts, see Buchsbaum and D'Esposito, 2008) Broca's area and Wernicke's area.

Pointer • A *pointer* can be a word, picture, gesture, etc. that "points" to one or more entities. It can be used in their place, e.g., if you "point" to a specific apple by saying "this apple," you do not have to actually take the apple in your hand to make it clear about which apple you are speaking.

Prefrontal cortex • The *prefrontal cortex* is part of the frontal lobe and can be understood as running a simulation of the world. It monitors social relationships, keeps track of objects when they are no longer visible (object permanence), and helps with the pursuit of long-term goals. It has only indirect connections to brain parts dealing with actions or sense perception.

Premotor cortex • The *premotor cortex* is part of the frontal lobe and prepares motor programs to be executed by the adjacent *primary motor cortex*. It has strong connections to the *superior parietal lobe* which provides a model of the current state of the limbs.

Primary motor cortex • The *primary motor cortex* is part of the frontal lobe and is directly adjacent to the primary somatosensory cortex of the parietal cortex. This way, it can directly process data from our sense of touch to better control movements. The *primary motor cortex* connects to the *brainstem* and *spinal cord* (via the *upper motor neurons*) which in turn connect to the muscles (via the lower motor neurons).

Primary somatosensory cortex • The *primary somatosensory cortex* in the parietal lobe deals with the processing of tactile sense input. Each body part is represented in the primary somatosensory cortex. The size of each representation correlates with the sensitivity of the body part to tactile stimulation (for example, lips and hands have a larger representation than other body parts).

Process • A *process* describes the mechanism of a cause working to an effect (e.g., if you put an ice cube into a glass of water, the cooling of the water is the process).

Procreation • *Procreation* is a process by which a system creates (on its own or with the help of the environment) a new entity with a similar or (preferably) the same structure as itself.

Property • A *property* refers to the manner in which an entity (or a process) affects other entities (or other processes) in a certain situation (e.g., mass, position, length, name, velocity, etc.).

Q

Quantum mind • The term *quantum mind* refers to a collection of theories that consider quantum mechanics as the basis of consciousness.

R

Rationalism • *Rationalism* is the attempt to create knowledge without induction and to deduce from this knowledge.

Rubber hand illusion • The *rubber hand illusion* can be evoked by brushing both a fake rubber hand and the real hand of a human participant. If only the fake rubber hand is visible, the brain will assume it is the real hand and incorporate it into its body schema.

S

Savannah hypothesis • The *savannah hypothesis* states that early humans evolved on the savannah and that many of the modern human's traits are a result of this adaption.

Selection (Evolution) • *Selection* is a process where some (or all) of a set of systems of similar structure are retained while the rest are discarded or destroyed. Which ones are retained and which ones are discarded depends on the relationship between the structure of the individual systems and the fitness landscape. In the example of the riddle screen, the screen lets small sand fall through while it "selects" larger stones.

Sense data • *Sense data* are information, converted to a form usable by cognition, about an effect registered by a sensory organ.

Split-brain syndrome • The *split-brain syndrome* can occur when the *corpus callosum* is damaged. This leads to problems with communication between the left and right brain hemispheres and complicates some tasks requiring both sides.

Structure • A *structure* is a description of required properties, dependencies, and arrangement of a number of entities (e.g., cube-shaped).

Subjective idealism • In the *subjective idealist* worldview, there is no such thing as "matter." Instead, everything is but perception, mind, or "consciousness," and nothing exists but human minds and gods.

Sulcus • A *sulcus* is a groove in the cerebral cortex.

Superior colliculus • The *superior colliculus* or *optic tectum* (in non-mammals) helps the eyes to track objects, and controls blinking, pupillary, and head-turning reflexes.

Superior parietal lobe • The *superior parietal lobe* deals with creating and maintaining a mental representation of the internal state of the body.

Supervised learning • Using *supervised learning*, a brain (or computer) can improve its response to a situation with each new encounter. For example, a dog can learn to sit or roll over on command by getting positive rewards for doing so during training.

Supramarginal gyrus • The *supramarginal gyrus* (SMG) creates an internal representation of the *limbs* of the body, similar to the adjacent superior parietal lobe (which creates a representation of the *internal state* of the body). It supports tool use (left SMG) and interpreting the emotional state of other people based on their postures and gestures (right SMG).

System • A *system* is an aggregate with a definite structure (e.g., an ice cube is a system of frozen water molecules).

T

Tabula rasa • *Tabula rasa*, (meaning "blank slate"), refers to the view that we are born without any innate knowledge and that our minds can create knowledge only with the help of sense data.

Temporal lobe • The *temporal lobe* is the part of the neocortex that deals with the "what": long-term memory, and object, face, and speech recognition.

Temporoparietal junction • The *temporoparietal junction* is a brain area between the temporal lobe and the parietal lobe, integrating data from the thalamus, as well as the limbic system, and the visual, auditory, and somatosensory systems. Combining the "what" and the "where" information, it creates a distinction between "self" and "other."

Term • A *term* is the name of a concept (e.g., as a word or fixed word combination, such as "goods and services" or "in a jiffy"). Every concept has a term pointing to it, but not every term is a concept (e.g., conjunctions like "and").

Thalamus • The *thalamus* integrates different sensory information and relays the information to other brain parts. For example, it combines sense data from the retinas' cones into colors, or calculates three-dimensional information from the two-dimensional images from both eyes.

Theory of Evolution • The *theory of evolution* states that the process of evolution tends to create systems in each new generation that are better adapted to the environment than the parent generation.

Theory of mind • The concept of *theory of mind* refers to the ability to imagine what other people (or animals) are thinking and what they know. This provides a significant advantage for hunting (predicting whether the prey can see or otherwise sense you), or social interaction (teaching, trading, and even lying, etc.).

Time • *Time* is a measurement tool to put the speed of processes in relation to each other.

Turing test • In 1950, Alan Turing proposed the *Turing test* to assess whether or not a machine is intelligent. In the test, a human participant would observe a text chat between a computer and a human. The machine would pass if the observer could not tell who was the machine and who was the human.

U

Uncanny valley effect • The *uncanny valley effect* refers to the negative reaction to dolls or robots that are very (but not fully) human-like. Possible reasons for this reaction are an inbuilt instinct to avoid corpses, and the inner conflict and discomfort of switching back and forth between seeing a being as fully human or a lifeless object.

Unsupervised learning • Using *unsupervised learning*, a brain (or computer) can build a concept by analyzing several sense perceptions, finding commonalities, and dropping measurements. For example, unsupervised learning could be used to form the concept "table" by encountering several different tables and finding out that they share properties like having a table-top, the form, material, and size of the table-top, and the number of table legs.

U

Viso-spatial scratchpad • The *visuo-spatial scratchpad* is responsible for temporarily storing visual and spatial information (involving the occipital lobes).

Von Neumann-Wigner interpretation • The *von Neumann-Wigner interpretation* of quantum mechanics tries to solve the loop of the Copenhagen interpretation by stating that consciousness is outside of the quantum world and is the final observer that collapses the wave function. For consciousness itself to exist, no observation of consciousness would be needed.

W

Wernicke's area • *Wernicke's area* is located in the left side of the temporal lobe. Its function is the *comprehension* of speech. Damage to Wernicke's area leads to people losing the ability to form meaningful sentences. It is connected to Broca's area, which is responsible for muscle activation to *produce* speech.

Working memory • *Working memory* is the collection of a number of different (limited) short-term memory systems in the brain. The prefrontal cortex has access to the working memory.

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Index

An Important Final Note

Writers are not performance artists. While there are book signings and public readings, most writers (and readers) follow their passion alone in their writing spaces at home, in a café, in a library, at the beach, or at a mountain retreat.

*What applause is for the musician, **reviews** are for the writer.*

Books create a community among readers; you can share your thoughts among all those who will or have read this book.

Please leave a thoughtful, honest review and help me to create such a community on the platform on which you have acquired this book. What did you like, what can be improved? To whom would you recommend it?

Thank you, also in the name of all the other readers who will be better able to decide whether this book is right for them. A positive review will increase the reach of the book; a negative review will improve the quality of the next book. I welcome both!

> If the human race develops an electronic nervous system, outside the bodies of individual people, thus giving us all one mind and one global body, this is almost precisely what has happened in the organization of cells which compose our own bodies. We have already done it. [...] If all this ends with the human race leaving no more trace of itself in the universe than a system of electronic patterns, why should that trouble us? For that is exactly what we are now!

—Alan Watts, The Book on the Taboo Against Knowing Who You Are