METAZOA

ANIMAL LIFE AND THE BIRTH OF THE MIND

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Dedicated to all who lost their lives in the Australian bushfires of 2019–20, and to the people who fought the fires

> And let me in this place movingly admonish you, ye ship-owners of Nantucket! Beware of enlisting in your vigilant fisheries any lad with lean brow and hollow eye; given to unseasonable meditativeness.... “Why, thou monkey,” said a harpooneer to one of these lads, “we’ve been cruising now hard upon three years, and thou hast not raised a whale yet. Whales are scarce as hen’s teeth whenever thou art up here.” Perhaps they were; or perhaps there might have been shoals of them in the far horizon; but lulled into such an opium-like listlessness of vacant, unconscious reverie is this absent-minded youth by the blending cadence of waves with thoughts, that at last he loses his identity; takes the mystic ocean at his feet for the visible image of that deep, blue, bottomless soul, pervading mankind and nature; and every strange, half-seen, gliding, beautiful thing that eludes him; every dimly-discovered, uprising fin of some undiscernible form, seems to him the embodiment of those elusive thoughts that only people the soul by continually flitting through it. In this enchanted mood, thy spirit ebbs away to whence it came; becomes diffused through time and space; like Wickliff’s sprinkled Pantheistic ashes, forming at last a part of every shore the round globe over.
>
> —HERMAN MELVILLE, *Moby-Dick; or, The Whale*

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PROTOZOA

Down the Steps

You walk ten steps down on a stairway shaped from breakwater rocks straight into the water, which is flat and still, right at the top of the tide. Sound recedes with gravity and light fades to soft green as you dip beneath the surface. All you can hear is your breathing.

Soon you are in a sponge garden, in a jumble of shapes and colors. Some of the sponges have the form of bulbs or fans, growing upward from the seafloor. Others spread sideways over whatever they find, in an irregular encompassing layer. Amid the sponges are what look like ferns and flowers, and also *ascidians* (with a silent "c"), pale pink spout-like structures with enamel patterns inside. The spouts resemble the downward-curved air funnels on the decks of ships, though these spouts face in every direction. They are covered by all manner of tangled life, often so encrusted that they appear to be part of the physical landscape in which things live rather than organisms in their own right.

But the ascidians make small shifts, as if asleep and half sensing you as you pass. Occasionally, and always startling me a little, an ascidian body half-collapses in place and visibly expels the water held inside the animal, as if with a shrug and sigh. The landscape comes to life and makes its own comment as you go by.

Among the ascidians are anemones and soft corals. Some corals take the form of a cluster of tiny hands. Each hand has the regularity of a flower, but a flower that grasps at the water around it. They clench and slowly open again.

You are swimming through something like a forest, surrounded by life. But in a forest, most of what you encounter is the product of a different evolutionary path: the plant path. In the sponge garden, most of what you see are animals. Most of those animals (all except the sponges themselves) have nervous systems, electrified threads that stretch through the body. These bodies shift and sneeze, reach and hesitate. Some react abruptly as you arrive. Serpulid worms look like tufts of orange feather fixed to the reef, but the feathers are lined with eyes, and they vanish if you come too close. One can imagine being in a green forest, and finding the trees sneezing and coughing, reaching out hands, glimpsing you with invisible eyes.

This slow swim out from shore is showing you remnants and relatives of early forms of animal action. You are not swimming into the past—the sponge, ascidian, and coral are all present-day animals, products of the same span of evolutionary time that produced humans. You are not among ancestors but far-removed cousins, distant living kin. The garden around you is made of the topmost branches of a single family tree.

Farther out and under a ledge is a tangle of feelers and claws: a banded shrimp. Its body, partly transparent, is just a few inches long, but antennae and other appendages extend its presence at least three times as far. This animal is the first I've mentioned that might see you as an object, rather than responding to washes of light and looming masses. Then a bit farther still, on top of the reef, an octopus is stretched out like a cat—a very camouflaged cat—with several arms extended and others curled. This animal watches you, too, more overtly than the shrimp, raising its head in attention as you pass.

Matter, Life, and Mind

Something was dredged from the depths of the North Atlantic by HMS *Cyclops* in 1857. The sample looked like seafloor mud. It was preserved in alcohol and sent to the biologist T. H. Huxley.*

The sample was sent to Huxley not because it seemed especially unusual, but because of an interest, both scientific and practical, in seafloors at the time. The practical interest stemmed from the project of laying deep-sea telegraph cables. The first cable to span and send a message across the Atlantic was completed in 1858, though it lasted only three weeks, when the insulation failed and the signal-carrying current leaked away into the sea.

Huxley looked at the mud, noted some single-celled organisms and puzzling round bodies, and stored the sample away for about ten years.

He returned to it then with a better microscope. This time he saw discs and spheres of unknown origin, and also a slime-like substance, a "transparent gelatinous matter," surrounding them. Huxley suggested that he had found a new kind of organism, of an exceptionally simple form. His cautious interpretation was that the discs and spheres were hard parts produced by the jelly-like matter itself, which was alive. Huxley named the new organism after Ernst Haeckel, a German biologist, illustrator, and philosopher. The new form of life was to be called *Bathybius Haeckelii.*

Haeckel was delighted with both the discovery and christening. He had been arguing that something like this must exist. Haeckel, like Huxley, was entirely convinced by Darwin's theory of evolution, unveiled in *On the Origin of Species* in 1859. Huxley and Haeckel were the leading advocates of Darwinism in their respective countries, England and Germany. Both were also eager to press on to questions that Darwin had been reluctant, beyond a few brief passages, to speculate about: the origin of life and the beginning of the evolutionary process. Did life arise just once on Earth, or several times? Haeckel was convinced that the spontaneous generation of life from inanimate materials was possible, and might be going on continually. He embraced *Bathybius* as a fundamental form of life, one that might cover large tracts of the deep seafloor; he saw it as a bridge or link between the realm of life and the realm of dead, inorganic matter.

The traditional conception of how life is organized, a picture in place since the ancient Greeks, recognized just two kinds of living things: animals and plants. Everything alive had to fall on one side or the other. When the Swedish botanist Carl Linnaeus devised a new scheme of classification in the eighteenth century, he installed plant and animal kingdoms alongside a third, inanimate realm, the "kingdom of rocks," or *Lapides*. This three-way distinction is still seen in the familiar question, "animal, vegetable, or mineral?"

By the time of Linnaeus, microscopic organisms had been observed, perhaps first in the 1670s by the Dutch draper Antonie van Leeuwenhoek, who made the most powerful of the early microscopes. Linnaeus included a fair number of tiny, microscopically observed organisms in his classification of beings, putting them in the category of "worms." (He concluded the tenth edition of his *Systema Naturae*, the edition that began the classification of animals as well as plants, with a group he called *Monas*: "body a mere point.")

As biology progressed, puzzle cases began to appear, especially at the microscopic scale. The tendency was to try to put them with either plants (algae) or animals (protozoa), on one side of the boundary or the other. But it was often hard to tell where some new creature belonged, and natural to feel that the standard classification was under strain.

In 1860, the British naturalist John Hogg argued that the sensible thing to do was to cease the shoehorning and add a fourth kingdom for the small organisms, increasingly recognized as single-celled, that are neither plants nor animals. These he called *Protoctista*, and he placed them in a *Regnum Primigenum*, or "primeval kingdom," that accompanied animals, plants, and minerals. (Hogg's term, *Protoctista*, was later shortened by Haeckel to the more modern *Protista*.) As Hogg saw it, the boundaries between the different living realms were vague, but the boundary between the mineral kingdom and the living was sharp.

The wrangling of categories I've described has so far been concerned with life, not with the mind. But life and the mind have long seemed linked somehow, even if their perceived relationship has not been stable. In the framework of Aristotle, developed over two millennia earlier, *soul* unifies the living and the mental. Soul, for Aristotle, is a kind of inner form that directs bodily activities, and it exists in different levels or grades in different living things. Plants take in nutrients to keep themselves alive—that shows a kind of soul. Animals do this and can also sense their surroundings and respond—that is another kind of soul. Humans can reason, in addition to the other two capacities, and so have a third kind. For Aristotle, even inanimate objects that lack souls also often behave in accordance with purposes or goals, tending toward their natural place.

The overthrow of Aristotle's picture in the seventeenth century's "Scientific Revolution" included a redrawing of these relationships. This involved a hardened conception of the physical—the assertion of a mechanical, push-pull view of matter with little or no role for purpose—and a lifting or etherealization of the soul. The soul, integral to all living nature in Aristotle, became a more rarified, intellectual affair. Souls may also be saved by divine will, permitting a kind of eternal life.

For René Descartes, an especially influential figure in this period, there is a sharp divide between the physical and the mental, and we humans are a combination of both; we are physical *and* mental beings. We succeed in being both because the two realms make contact in a small organ in our brains. This is Descartes's "dualism." Other animals, for Descartes, lack souls and are purely mechanical—a dog is without feeling, no matter what is done to it. The souls that make humans special are no longer present, even in faint forms, in animals and plants.

In the nineteenth century, the time of Darwin, Haeckel, and Huxley, advances in biology and other sciences made dualism of Descartes's kind look less and less viable. Darwin's work suggested a picture in which the divide between humans and other animals is not so sharp. Different forms of life along with different mental powers might arise through gradual processes of evolution, especially by adaptation to circumstances and the branchings that originate species. This should suffice to explain both bodies and minds—if you can get things started.

That was a big *if*. Haeckel, Huxley, and others approached this part of the problem as follows. They thought there must be a *stuff*, present in living things, that enables both life and the beginnings of a mind. This stuff would be physical, not supernatural, but quite unlike ordinary matter. If we could isolate it, you could pick up a spoonful of it, and in your spoon it would still be the special stuff. They called it "protoplasm."

This might seem an odd approach, but it was motivated in part by close inspection of cells and simple organisms. When people looked inside cells, it seemed that not enough organization was present—not enough parts were different from other parts—for cells to do what they are evidently able to do. What they saw seemed to be just a substance, transparent and soft. The English physiologist William Benjamin Carpenter, writing in 1862, marveled at what single-celled organisms could achieve: the "vital operations" that one sees "carried on by an elaborate apparatus" in an animal are instead brought about by "a little particle of apparently homogeneous jelly." The particle of jelly is seen "laying hold of its food without members, swallowing it without a mouth, digesting it without a stomach," and "moving from place to place without muscles." This led Huxley, and others, to think that it could not be an intricate organization of ordinary matter that explains living activity, but a different ingredient, one that was inherently alive: "organization is the result of life, not life the result of organization."

Against that background, *Bathybius* seemed extraordinarily promising. It appeared to be a pure sample of the stuff of life, stuff that perhaps arises spontaneously all the time, forming an ever-renewing deep-sea organic carpet. Further samples were examined. *Bathybius* obtained from the Bay of Biscay was described as being capable of movement. Other biologists were not so sure about this alleged primordial life-form, however, and the growing mass of speculation around it. How was *Bathybius* staying alive down there? What might it eat?

Then came the *Challenger* expedition—a four-year project organized by the Royal Society of London in the 1870s that took samples from hundreds of deep-sea sites around the world. The aim was the first comprehensive inventory of life in the deepest waters. The chief scientist on the expedition, Charles Wyville Thomson, was willing to work on the *Bathybius* question although he was wary of it. No fresh samples were found by the *Challenger*, and two scientists aboard the ship began, amid some tinkering, to suspect that *Bathybius* was not alive and not even close to it. With a series of experiments, they showed that *Bathybius* appeared to be nothing more than the product of a chemical reaction between seawater and the alcohol used to preserve samples, including Huxley's old sample from the HMS *Cyclops.*

Bathybius was dead. Huxley acknowledged his error immediately. Haeckel, more committed to *Bathybius* as a missing link, hung on, unfortunately, for nearly ten more years. But the bridge had failed.

Afterward, some people still held out hope for a bridge of roughly the same kind—a special substance that would link life with matter. But in the years that followed, views of that kind subsided. They were replaced in a slow process of discovery, a process that eventually made living activity no longer mysterious. The resulting explanation of life proceeded in exactly the way that Huxley and Haeckel could not countenance: in terms of the hidden organization of ordinary matter.

That matter is not "ordinary" in every sense, as we will see, but it is ordinary in its basic composition. Living systems are made of the same chemical elements that make up the rest of the universe, running according to physical principles that extend also into the inanimate realm. We don't presently know how life originated, but its origin is no longer a mystery of a kind that might make us believe that some extra substance generates the living world.

This has been the triumph of a *materialist* view of life—a view that permits no supernatural intrusions. It was also the triumph of a view that sees the physical world itself as unified in its basic constituents. Living activity is not explained in terms of a mysterious ingredient, but in terms of intricate structure on a tiny scale. That scale is almost inconceivable. To pick just one example, ribosomes are important parts of cells —the stations where protein molecules are assembled—with a rather complex structure of their own. But over 100 million ribosomes could fit on the period printed at the end of this sentence.

Life, then, has fallen into place. In the case of the mind, much less is resolved.

The Gap

From the late nineteenth century onward, with Darwin's revolution gathering steam, it seemed hard to maintain a dualist view of the mind like Descartes's. Dualism makes some sense within an overall picture that locates humans as a unique and special part of nature, close to God in some way. Then all the rest, alive or dead, can be purely material, while we have an added ingredient. An evolutionary perspective on humanity, one that sees continuities between ourselves and other animals, makes dualism difficult, though not impossible, to maintain. This motivates the attempt to develop a materialist view of the mind, one that explains thought, experience, and feeling in terms of physical and chemical processes. The fact that life itself succumbed to a materialist treatment of this kind is encouraging, but it is not clear how much it really helps; it's not clear what relationship the success of materialism in biology has to the puzzles of the mind.

Looking again at the history, we can distinguish two alternative paths that continue through to the present. Aristotle, as we saw, recognized several different grades of soul, linking plants, animals, and ourselves. What we call "mind" is viewed as a natural extension, or version, of living activity. Aristotle's view was not an evolutionary one, but it is not too hard to recast such a picture in evolutionary terms. The evolution of complex life naturally gives rise to the mind, through the growth of purposeful action and sensitivity to the environment.

Descartes, in contrast, saw life as one thing and mind as entirely another. There is no reason, in this second view, to think that progress in understanding life will make much of a difference to problems about the mind.

Over the last century or so, most views in this area have been materialist, but in one respect they have moved close to Descartes. From the mid-twentieth century onward, theorists shifted away from seeing close connections between the nature of life and the mind. This was encouraged by the advance of computers. Computer technology, as it developed from the middle decades of the last century, promised a different bridge between the mental and the physical, a bridge made of logic rather than life. The new mechanization of reasoning and memory—computation—seemed a better way forward. As artificial intelligence (AI) systems developed, some of them started to seem a bit intelligent, but there was little reason to think of them as *alive*. Animal bodies, it seemed, did not matter very much—they came to appear entirely optional, in fact. Software was the heart of the matter. The brain runs a program, and that program might run on other machines (or things other than machines) as well.

These years also saw a sharpening of the problem of mental and physical. "The mind" as puzzle was replaced by a more specific conundrum. The new view holds that some of the mind can be fairly readily explained in materialist terms, while another aspect is more resistant. The resistant side is subjective experience, or consciousness. Consider memory, for example. We might find that various kinds of animals have memory; they create traces of the past in their brains, and use those traces later, when working out what to do. It is not too hard to imagine how brains might achieve this. Much of that problem is unsolved, but it certainly looks soluble; we should be able to work out how this side of memory works. But in humans, at least, some kinds of memory also *feel* like something. As Thomas Nagel put it in 1974, there is *something it's like*—something it *feels* like—to have a mind. There is something it feels like to remember a good experience, or a bad one. The "information-processing" side of memory, the ability to store and retrieve useful information, might either be accompanied by this additional feature or not. The hard part of the mind-body problem is explaining that last side of our mental lives, explaining in biological, physical, or computer-based terms how felt experience can exist in the world.

This problem is often still approached through a range of classic options. The main divide has materialist (or "physicalist") views on one side, and dualism on the other. More radical possibilities are also entertained. *Panpsychism* holds that all matter, including the matter in objects like tables, has a mental aspect to it. This is not the idea that the entire universe is made of experience—that is *idealism*. Instead, a panpsychist accepts the physical layout of the world as it appears, but adds that the material that makes up that world always has a side to it that is faintly mind-like. This mind-like side of matter gives rise to experience and consciousness, once some of that matter is organized into brains. Despite its apparent extravagance, panpsychism has serious defenders. Thomas Nagel, who I mentioned above, argues that panpsychism should be kept on the table as an option, because every view has significant problems and panpsychism's problems are no worse than others'. Ernst Haeckel, in the post-bathybius years, was also attracted to panpsychism. Huxley was attracted to another unorthodox view. He suspected that conscious experience might be an effect of material processes, but never a cause of them. This is an unusual kind of dualism, and it also has defenders today.

Something that is vivid in the wild sweep of these alternative views of the universe, and visible also in more mundane discussions, is a huge diversity in ideas about where minds are to be found. For some, mind is everywhere, or nearly everywhere. For others, it is confined to humans and perhaps a few animals similar to us. One person will look at a paramecium, a single-celled organism, swimming vigorously through a film of water and say: What is going on in that creature is enough for it to have feelings. The paramecium is responsive, and has goals. On a tiny scale, it has experience. Another person will not merely dismiss the paramecium, but will look at a complex animal, like a fish, and say: There is probably no feeling there at all. The fish has a lot of reflexes and instincts, and some fairly complicated brain activity, but all of this activity is going on "in the dark." If this second person is wrong, why are they wrong? If panpsychism is also wrong and there is no hint of feeling in a grain of sand, why is *that* wrong? *Might* things be that way? There often seems to be a kind of arbitrariness in the situation. People can say whatever they like. If I were to guess where most people stand at the moment, when asked which living things around them have experiences, I would conjecture that a common answer is "yes"for mammals and birds, "perhaps" for fish and reptiles, and "no" for everything else. But if someone insists on pushing further out (to ants, plants, and paramecia) or pulling further in (mammals only), the discussion rapidly gets a bit untethered. How could we possibly work out who is right?

This sense of arbitrariness is related to something the philosopher Joseph Levine has called "the explanatory gap." Even if we come to be pretty sure that the mind must have a purely physical basis, with nothing added, we would also want to know why *this* physical setup gives rise to *this* kind of experience, rather than something else. Why does it feel like *this* to have a brain of the particular kind you have, going through the processes it is going through right now? Even if the difficulties faced by other views convince us that materialism has to be true, it's hard to see *how* it's true, how things could be this way.

That is the cluster of problems I want to address in this book. The aim is not to answer Levine's questions about particular experiences—which activities of the brain are involved in seeing color or feeling pain. That is a task for neuroscience. The aim, instead, is to make sense of why it feels like something to be a material being of the kind that we are. That "we" is intended to be rather broad; my main target is not the intricacies of human consciousness, but experience in general, something that might extend to many other animals. I want to address these questions about experience in a way that reduces the sense of arbitrariness I described above—the feeling that you could say yes to bacteria, no to birds, whatever strikes you.

The approach I take to the mind-body problem is biological, and one that fits into a materialist picture of the world. The word "materialism" to many suggests a hard-headed, tough-minded view: the world is smaller than you thought, less special or less sacred, just atoms bumping into each other. Atoms bumping into each other are indeed quite important, but I do not want to get the story moving with a mood of toughness and restriction in the air. The "physical" or "material" world is more than a world of thudding collisions or dry structure. It is a world of energy and fields and hidden influences. We should be ready for ongoing surprises about what it contains.

The approach taken in this book is a biological materialism, but in many ways the heart of my outlook is a broader position, sometimes called *monism*. Monism is a commitment to an underlying unity in nature, a unity at the most basic levels. Materialism is one kind of monism, as it is committed to the idea that mental phenomena, including subjective experience, are manifestations of more basic activities described in biology, chemistry, and physics. Idealism, the idea that everything is mental, is another kind of monism—it is a different assertion of unity. (An idealist must explain how what seem to be physical objects and goings-on are really manifestations of mind or spirit.) Yet another way of being a monist is to think that both what we call the "physical" and what we call the "mental" are manifestations of something else that is basic; this view is called *neutral* monism. Rather than explaining the mental in physical terms or explaining the physical in mental terms, we explain both the physical and mental in terms of something else. That "something else" tends to remain rather mysterious. If I was not a materialist I'd be a neutral monist, but that is an outside possibility for me. The way I will proceed is by starting with life—understood in a materialist way—and trying to show how the evolutionary development of living systems can give rise to minds. I want to close—partially, at least—the explanatory gap between mental and physical.

Before we proceed, however, let's take a closer look at the mental side of the puzzle, and the words we use to describe it. The side of the mind that Nagel tried to point to by saying "there is something it's like..." is now often called *consciousness*. (Nagel himself calls it that.) You are conscious, in this sense, if there is something it feels like to be you. But the term "consciousness" is often misleading here, as it tends to suggest something quite sophisticated. That phrase "something it's like..." is supposed to include the presence of feelings of any kind. There is something it feels like to be you—or a fish, or a moth—if the vaguest, dimmest washes of sensation are part of your life. The fact that the word "consciousness" suggests more than this tends to cause trouble.

For example, neuroscientists often say that consciousness depends on the cerebral cortex, the folded part at the top of our brains, something found only in mammals and some other vertebrates. Here is a quote from the physician and essayist Oliver Sacks, talking about a patient who had, as a result of a brain infection, lost all ability to hold new events in memory. Sacks asked: "What is the relationship of action patterns and procedural memories, which are associated with relatively primitive portions of the nervous system, to consciousness and sensibility, which depend on the cerebral cortex?" Sacks is asking a question here, but also stating an assumption: that consciousness and sensibility depend on the cerebral cortex. Does Sacks mean that if someone or something lacks a cerebral cortex, they will lack consciousness in its here-I-am richness, but might still have some feelings? Or does he think that without a cortex the lights are completely off, and any such being would have no experience at all, even if it could manage some behaviors? Most animals, especially most of the animals in this book, do not have a cerebral cortex. Do they have experience of a different kind from us, or no experience at all?

Some people do think that without a cortex there can be no experience at all. Perhaps we will be pushed to a view like this in the end, but I doubt it. We need to continually avoid falling into the habit of thinking that all forms of experience must be human-like in various ways. When the word "consciousness" is used for the very broad idea of felt experience, it is easy to go astray. But many people do now use the word "consciousness," or some modification of it ("phenomenal consciousness"), in this very broad manner. I am not going to be fussy about the words, and no terminologies are perfect. In some ways, "sentience" is a good term for the broader concept. We can ask: Which animals are sentient? This is, or might be, different from asking which ones are conscious. But "sentience" is often used for particular *kinds* of experience—for pleasure and pain and related experiences that include a valuation, good or bad. Those experiences are certainly important, and it probably makes sense to think that they can exist without sophisticated kinds of consciousness. But these may not be the only kinds of basic or simple experience. In a later chapter, I will look at the possibility that sensory and evaluative sides of experience are somewhat distinct—registering what is going on might be distinct from evaluating whether it is good or bad. "Sentience" is not usually used for the sensory side of this distinction.

Another term is the unwieldy "subjective experience." The term looks redundant (is there another kind of experience?) and it has no easy adjective, like "conscious" or "sentient." But "subjective experience" points in a good direction, by calling up the idea of a *subject*. In some ways this book is about the evolution of subjectivity—what subjectivity is and how it came to be. Subjects are the home of experience, where experience lives.

I will also talk sometimes just about the mind, as I think that is what we come to understand through this story: the evolution of the mind and how it fits into the world. I'll move between terminologies without laying down the law. Our present understanding is not good enough to insist on one language or another.

The project I am trying to advance can be described in a number of different ways, but it is difficult no matter how we look at it. This project is to show that somehow a universe of processes that are not themselves mental, or conscious, can organize themselves in a way that gives rise to felt experience. Somehow, a part of the world's often-mindless activity folded itself into minds.

Dualism and panpsychism and various other views think that this cannot happen; you can't make a mind—not wholly, anyway—from something else, from entirely non-mental ingredients. Mind must be present in everything, or it has to be added "on top"—not literally on top, but added to a physical system that would be complete, in principle, without it. I think, instead, that you can—or evolution can—build a mind from something else. Given some arrangements of things that are not themselves mental, a mind comes to exist. Minds are evolutionary products, brought into being by the organization of other, non-mental ingredients in nature. That coming into being is the topic of the book.

I said that mind is an evolutionary product and something *built*, but I want to prevent a common mistake from arising right away. A materialist view does not claim that the mind is an *effect* of physical processes in our brains, a consequence or product of them. (Huxley seems to have thought that.) The idea, instead, is that experiences and other mental goings-on are biological, and hence physical, processes of a certain kind. Our minds are arrangements and activities in matter and energy. Those arrangements are evolutionary products; they are slowly brought into being. But those arrangements, once they exist, are not *causes* of minds; they *are* minds. Brain processes are not causes of thoughts and experiences; they *are* thoughts and experiences.

That is the biological materialist project as I see it—showing that such a position makes sense, and is, most likely, how things actually are. The aim of this book is to work as far as I can down this path. I don't think a solution to the problem will be revealed in a single stroke of the pen, in a move that pulls a rabbit from a hat. It will be more cumulative. As this book moves along, I will develop a positive view, a sketch of a solution that combines roughly three elements in a picture that I think makes sense. But not every question will be answered, and many puzzles will remain. The way I think things will go is vividly expressed in a passage that through years of drafts I had as an epigraph to this book. The passage is by Alexander Grothendieck, a mathematician.

> The sea advances insensibly and in silence, nothing seems to happen and nothing is disturbed.... But it finally surrounds the stubborn substance, which little by little becomes a peninsula, then an island, then an islet, which itself becomes submerged, as if dissolved by the ocean stretching away as far as the eye can see.

Grothendieck worked on very abstract problems—abstract even by the standards of pure mathematics. The quote describes his approach to problems in his field. A puzzle in front of us seems to resist the usual methods. What we should do in response is build knowledge *around* it, expecting that as we do this, the puzzle will transform and disappear. The situation becomes reshaped and eventually comprehensible. The image he used for this process is the submerging of an object, a mass, in water.

I have had that image in my mind for a long while now. I don't think, as some philosophers do, that the puzzles in this area are mere illusions that we can overcome if we just talk a bit differently. New things have to be learned. But as they are learned, the problem itself changes shape and fades.

Grothendieck's image seemed so apt that I once used it to head the book. But the image has new connotations now, at a time when the melting polar ice of a rapidly warming Earth is leading to the loss of precious Pacific islands. Given these new associations, it seemed wrong to begin the book that way. But Grothendieck's metaphor does still guide my thinking, and the perspective expressed there guides how the book will work. *Metazoa* approaches the puzzles of mind and body by exploring the nature of life, the history of animals, and the different ways of being an animal that surround us now. By exploring animal life, we build around the problem and see it transform and subside.

This book is a continuation of a project that began in another, called *Other Minds*. That book was an exploration of evolution and the mind guided by a particular group of animals: cephalopods, the group that includes the octopus. *Other Minds* began with encounters with these animals in the water, scuba diving and snorkeling.

Encountering them there, in their protean, color-warping complexity, led to an attempt to understand what might be going on inside them. That led, in turn, to a tracing of their evolutionary path, a path taking us to a pivotal event in the history of animals, an ancient fork in the genealogical tree. That fork, over half a billion years ago, led on one branch to the octopus (among others), and on the other branch to us.

Some ideas about minds, bodies, and experience were sketched in that book, guided by the animals I was following. Here, those ideas are developed and augmented. That development comes as a result of a closer look at the philosophical side, an exploration of further branches of the tree, and watery hours spent with more of our animal relatives. Whereas in *Other Minds* I kept coming back to octopuses, my aim in this book is to move along with many kinds of animals, both closer and further from us on the evolutionary tree. For some of those animals I, too, was a being they could observe and encounter; for others, a presence in less than a dream. Toward the end of the book, we begin to approach nearer relatives, with bodies and minds more like our own. But the historical story is weighted to the earlier evolutionary stages, and its goal is to make sense of how experience came to exist on Earth at all, first in its waters, later on land.

That, then, is the path of the book. We walk—crawl, grow, swim—through the story of animal life from its beginnings, guided by a collection of present-day creatures. We learn from each animal—from its body, how it senses and acts, how it engages with the world. With their aid, we try to discern not just the history, but the different forms of subjectivity around us now. My goal is not encyclopedic, trying to cover every variety of animal. I concentrate on those that mark transitions in the evolution of the mind, especially the stages by which it came to be. Most of these are marine animals, living in the sea. Let’s walk down the steps.

2

THE GLASS SPONGE

Towers

A sponge garden often begins just below the layers of water that sunlight penetrates well, especially in places where currents flow. There, as light falls away, you may find a landscape of motionless animal bodies. They have the appearance of cups, bulbs, grails, or branching trees. Sometimes they look like hands in thick mittens, as if something huge beneath the seafloor was trying to reach upward with soft, half-made limbs.

While in this shallow zone, look out and imagine a sea much colder, the scene now a blackness with a thin fall of particles from above. On the ocean floor, 3,000 feet below the surface, a pale tower, about a foot tall and cylindrical, sits in a cluster of other towers, each held fast at the bottom and a little broader, partly open, at the top. Within its soft exterior is a lattice of tiny hard parts. The smallest of these are stars, hooks, or slender crosses, with angles skewed to knit into that tower-like form. The towers are held to the seafloor by delicate anchors. The anchors and crosses are made of silicon dioxide, the main constituent of glass.

A sponge, on a temperate reef or a deep ocean moonscape, looks dead and inert, but if you look closely, it is not. It is a silent pump, drawing water through itself. As it does so, it senses and responds. The deep-sea tower, the glass sponge, has a body that also conducts light and charge, like an electric light bulb ("think!") at the bottom of the sea.

Cell and Storm

The background to the evolution of the mind is life itself—not everything about life, not DNA and its workings, but other features. The start is the cell.

Early life, before animals and plants, was single-celled. Animals and plants are huge collaborations of cells. Before those collaborations arose, cells were probably not entirely solitary, but often lived in colonies and clumps. Still, a cell then was a tiny self of its own.

Cells are bounded, with an inside and outside. The border is a membrane; it partially seals the cell but has channels and ports embedded in it. A continual to-and-fro runs across that border, and inside is a frenzy of activity.

A cell is composed of matter, a collection of molecules. I don't know exactly what comes into your head when I say "matter," but the word often brings to mind an inert, ponderous way of being, with weighty objects needing to be pushed into motion. That picture of matter is guided by how things work on dry land and at the scale of midsize objects like tables and chairs. When we think of the material of a cell, we need to think differently.

Inside a cell, events occur on the *nanoscale*, the scale at which objects are measured in millionths of a millimeter, and the medium in which things happen is one of water. Matter in this environment behaves differently from anything in our midsize, dry-land world. At this scale, activity arises spontaneously, without having to be made to happen. In a phrase due to the biophysicist Peter Hoffmann, within any cell is a "molecular storm," a ceaseless turmoil of collisions, attractions, and repulsions.

If we imagine a cell full of intricate apparatus, parts with jobs to do, these devices are continually being bombarded by water molecules. An object in a cell has a fast-moving water molecule collide with it about every ten trillionth of a second. That's not a typo; the scale of events in a cell is almost impossible to think about in an intuitive way. Those collisions are not trivial; each has a force that dwarfs the forces those devices can themselves exert. What the apparatus inside a cell can do is nudge events in one direction rather than another, bringing some coherence to the storm.

The medium of water is important in maintaining this storm. Many objects at this spatial scale would stick together and seize up in a clump if they were out on dry land, but do not seize up in water; instead they're kept in motion, and this makes the cell a realm of self-generated activity. We often think of "matter" as inactive and inert, I said. The problem cells have to deal with, though, is not getting things to happen, but creating order, instituting some rhyme and reason in the spontaneous flow of events. Matter, in these circumstances, does not sit there doing nothing, but risks doing too much; the problem is getting organization out of chaos.

Nearly all the associations we habitually bring to bear when we think about matter are misleading when we consider life and how it might arise. If life had to evolve on dry land out of table-and-chair-sized ingredients, it could not happen. But life did not have to do this; it evolved in water—perhaps in thin films of water on a surface, but in water—through the emergence of order in a molecular storm.

The origin of life occurred fairly early in the history of Earth, perhaps around 3.8 billion years ago, on a planet now about 4.5 billion years old. The first life may not have been cell-shaped, but there must have been some initial way for a special set of chemical processes to be contained, marked off, and prevented from diffusing away. Then at some stage there were cells, presumably leaky and tenuous at first, but eventually arriving at something like bacteria, cells that consistently maintain their organization and reproduce.

As cells acquired the power to keep themselves going—transforming materials, imparting order, bringing method to madness—a central achievement was gaining control over charge.

The Taming of Charge

The taming of electric charge was a pivotal event in recent human history. In the nineteenth century, electricity went from being a mysterious, often dangerous force—encountered most directly in lightning—to an element in technologies that soon formed the modern world. If you are reading this book under electric light or on a computer, the act of reading is electrically sustained. This modernizing electrical advance was the second of two. Charge was also tamed billions of years before, during early stages of life's evolution. In cells and organisms, electricity is the means by which much of what happens is done. It is the basis for brain activity—our brains are electrical systems—and also a great deal else.

What *is* electricity? Even many physicists find this question elusive. Electric charge is a basic feature of matter. Charge can be positive or negative. Objects with the same charge (positive and positive, for example) repel, and those with unlike charges (positive and negative) attract. The stuff of ordinary objects contains both. Any atom is a combination of even smaller particles, some that are positive (protons), others that are negative (electrons), and in most cases, other particles (neutrons) with no charge. Usually, an atom will contain the same number of electrons as it has protons, so the atom itself will have no net charge, as the positive and negative charges within it are exactly balanced.

The electrical tendency to attract and repel is strong. Here is the inimitable Richard Feynman, in his *Lectures on Physics.*

> Matter is a mixture of positive protons and negative electrons which are attracting and repelling with this great force. So perfect is the balance, however, that when you stand near someone else you don't feel any force at all. If there were even a little bit of unbalance you would know it. If you were standing at arm's length from someone and each of you had *one percent* more electrons than protons, the repelling force would be incredible. How great? Enough to lift the Empire State Building? No! To lift Mount Everest? No! The repulsion would be enough to lift a "weight" equal to that of the entire earth!

In the mix of charged parts that comprises ordinary matter, electrons, the negative particles, are on the outside of atoms, while protons (along with neutrons) are on the inside. Electrons on the outside can sometimes be gained or lost, resulting in an *ion*. An ion is an atom (or sometimes a molecule that combines a few atoms) that has unbalanced its charged parts through such a loss or gain, and hence has an overall charge of its own. When many chemicals dissolve in water, they produce ions that then drift around. *Salt* water is water with dissolved ions. Any droplet of seawater will contain countless ions, interacting with each other and with the water molecules, attracting and repelling.

An electric *current* is a movement of charged particles, either positive or negative. In a metal wire, a current takes the form of a movement of electrons, with the rest of each atom making up the wire remaining in place. The electric currents used in technology (lights, motors, computers) mostly work in this way. But a current can also be a movement of whole ions. If some positive or negative ions in water, for example, can be induced to move in a consistent direction, that is an electric current. It does not make a current flow; it *is* one. Any container of salt water can contain such a current, if you can somehow get an overall pattern of movement of ions of the right kind to occur. In living systems, unlike human inventions, most currents take this form.

Charge is not life-like or mental in itself. It produces much of what happens in the inanimate world as well as the animate. But living activity runs on charge, especially by the corralling, pumping, herding, and unleashing of ions.

A cell's membrane keeps many things either outside or inside, but it contains channels that selectively let some material through. Many of these are *ion channels*. Sometimes a channel will passively allow ions to move from one side to the other, perhaps under specific circumstances; in other cases, the cell pumps the ions across the membrane.

Ion channels are shared, with variations, across all kinds of cellular life, including bacteria. The reasons for bacteria to build elaborate ports and passageways for ions are often not entirely clear. Channels may have arisen initially just to enable cells to adjust their overall charge in relation to the outside—tuning as well as taming their charge. Whenever there is traffic across a living system's boundaries, though, it tends to take on further roles. A flow of ions can function as a minimal form of sensing, for example: suppose contact with a particular external chemical opens a channel and lets in ions. Those charged particles can set new events in the cell in motion.

The next consequence of these ion flows is related to that to-and-fro traffic, but is a larger, more wholesale change to the cell. This next step is *excitability*. Channels control the flow of charged particles, and these channels can themselves be controlled: they can be opened or closed. This can happen through chemistry, or physical impact, but it can also involve charge itself. Voltage-gated ion channels are channels that open as a response to electrical events that they, the channels, are exposed to. This makes possible a chain reaction; a flow of current creates a greater flow of current, one that spreads over the cell membrane.

This might not seem much of a step, and it has less of an obvious ring of usefulness than the arrangement I described above, where the flow of ions is sensitive to chemicals the cell encounters in its travels. But voltage-gated ion channels are the basis for another innovation, the *action potential*. This is a moving chain reaction of changes to the membrane of a cell, especially in our brains. Positive ions flow into the cell at one point, affecting ion channels at adjacent points, which open and allow more ions to come in, and so on. A wave of electrical disruption travels along the membrane like a pulse. An action potential is the zap-like event that is described as a brain cell "firing." That zap happens by means of voltage-gated ion channels.

In a voltage-gated ion channel, a controller of current is affected by charges it is exposed to; the flow of current is electrically controlled. This is the principle of a transistor. At the start of this section I mentioned the nineteenth-century advances that brought electricity into the realm of human technology. Another such advance occurred in the twentieth century, with the invention of the transistor. The silicon chips in computers and smartphones are collections of tiny electrical switches of this kind. The transistor was invented around 1947 at Bell Laboratories in the United States—or invented once then, anyway. The first Bell Lab transistor was an inch or so in size, and it has been continually refined and shrunk since then. The same device was invented billions of years ago in the evolution of bacteria.

If bacteria invented transistors, what were they doing with them? Why did *they* need to control electricity with electricity? As far as I can tell, no answer to this question is widely agreed on. Bacteria might have been using them as part of the electrochemical upkeep of the cell. They might have been used in the control of swimming. Channels that sense external chemicals may be incidentally sensitive to charge, and bacteria that form colonies in "biofilms" signal from cell to cell using ions. But bacteria don't have action potentials—the zap-like chain reactions in our brains—and the situation does seem quite odd to me. Several billion years ago, nature invented the fundamental hardware device in computer technology—a complicated and costly device, too—and did so in bacteria, but bacteria do not seem to have been doing much computing with it.

Regardless of why it arose, the voltage-gated ion channel was a landmark in the taming of charge. These channels do not have a single obvious use, I said above. In a sense, neither does a transistor, and in both cases, that is part of their importance. A transistor is a general means for control, a device for making events *here* affect events *there* in a reliable, rapid way. The events controlled can be multifarious—whatever might be useful. When they enable action potentials, voltage-gated ion channels also make it possible for a cell's activity to have a "digital" quality; a neuron either fires or

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