8 Convergent Evolution of the Umwelt

The world as we experience it is strikingly ordered. Features of the surrounding environment do not insensibly grade into one another, nor are they jumbled in a chaotic maelstrom of incoming sensory data. Rather, we find ourselves situated at the center of a field of discrete objects. Each object is bound with various properties (such as shape, color, and motion) and retains its identity over space and time. This object-structured phenomenal field is somehow seamlessly stitched together in the brain and "presented" to the subject of experience, which has little choice but to take it all in. Our unified model of the external world is updated in real time as we navigate a meaningful landscape, incorporating feedback and filling in perceptual gaps to maintain a stable scene, which in turn guides active, purposeful behavior.

This is how we, and probably many other animals, experience the world at very coarse grains of resolution: namely, as a unified field of property-bound objects distributed over space and time. This chapter and the next two chapters will argue that the core structure of experience—the unified phenomenal field—is evolutionarily primitive, convergently derived, and likely to be a cosmically projectible property of the living universe. Precisely why the structure of experience is constrained in this way is unknown. Possible explanations range from constraints imposed by the external world to computational limitations that are inherent to cognition itself. There is clearly much philosophical territory to be explored; yet when all is said and done, most of the landscape will remain uncharted, and the mystery of mind will remain.

1. The Deep Structure of Experience

The phenomenal scene is unified in several respects. First, it is experienced as a single whole that cannot be decomposed into its phenomenal constituents. For example, the scene cannot be parsed into separate experiences of shape, color, or motion, or even into separate experiences of distinct objects. The components of conscious experience have what the philosopher Tim Bayne calls a "conjoint phenomenal character": they are contained within and subsumed by the larger phenomenal scene, which presents to the subject as a single global tapestry bound in time.[1]

Second, object percepts within the scene are individually unified in that they exhibit the same phenomenal holism or decomposability that can be attributed to global experience. Our experience of an apple, for instance, cannot be decomposed into experiences of shape and texture and color. Borrowing a term from modern aviation, we can call the simultaneous experience of numerous bound objects of the phenomenal scene "situational awareness": the ability to situate the self (or one's body) in the midst of the dynamic, fluctuating flow of the phenomenal field by simultaneously keeping track of multiple object variables and interrelations. The more entities that can be experienced synchronically and tracked diachronically, the richer the situational awareness of the subject.

Third, consciousness is unified in the sense that the phenomenal scene cannot be divided into multiple separate points of view. For instance, there are some indications that patients whose corpus callosum (the band of nerve fibers that functionally integrates the two hemispheres of the brain) is severed experience the world as two separate, unified subjects of experience, each with their own exclusive first-person perspective (more on this later). Splitting a unified subject of experience appears to result in multiple unified experiencers, each with an inner world that is inaccessible to the other.

A fourth aspect of experiential unity is stability: the phenomenal scene is remarkably coherent despite incongruities among incoming streams of sensory data. For instance, even though each eye has a slightly different view of the world, and even though objects may be partially occluded by clutter in the environment, the scene as we experience it is smooth and coherent. The phenomenon of bistable percepts (such as the "duck-rabbit"), which applies also to auditory and olfactory experiences, lends additional credence to the notion that experience is not decomposable into its basic elements. We can only experience the world in one way at a time; this experience is immediate, and its character is accessible only to the embodied subject.

The main contention of part II is that the unified structure of experience is not a radically contingent accident of human, primate, or even vertebrate evolution. Rather, it is a law-like feature of the evolutionary process that is intimately connected to the emergence of image-forming sensory modalities (ISMs). We saw in the previous chapter that the ISM transcends both phylogenetic constraints and the boundaries of sensory modalities traditionally conceived. The present chapter will make a similar case for the unified phenomenal world—or what I will call the "Umwelt" (a term coined by Jakob von Uexküll that I will adapt to the evolutionary context)—whether this concept is cashed out phenomenologically or in more tractable terms like representation. This chapter will focus on the conceptual dimensions of Umweltian cognition and consciousness. Empirical evidence for the convergent evolution of Umweltian minds will be explored over the next two chapters.

2. Umweltian Cognition and Consciousness

The term "Umwelt," which was coined by theoretical biologist Jakob von Uexküll in the early 1900s, literally means "the world around."[2] The Umwelt is a first-personal portal on the world, an internal model of meaningful objects in the surrounding environment as interpreted through an organism's peculiar set of neurocognitive and sensory apparatuses. The notion of Umwelt that will be deployed here differs in a number of respects from the term as it was originally conceived, though I hope to retain some of the elegance and utility of the original.

2.1 Adapting a Nonevolutionary Concept

At the core of the original Umwelt theory is the notion that there is a "semiotic" relationship between the subject of experience and its surrounding environment. That is to say, each species bears its own relationship of meaning and interpretation to the external world, and this constructed relationship of meaning is the primary means through which species interact with the world around them. The Umwelt is essentially an inner model of the external world which, according to von Uexküll, remains in itself unknowable. Von Uexküll conceives of the Umwelt as a broad-based biological phenomenon, one that does not require linguistic or other high-level cognitive capacities. Umwelten vary in content from species to species, depending on the "meaning organs" (senses and processing powers) they possess, which in turn are teleologically designed to detect aspects of the external world that are relevant to an organism's particular lifeways. Animals are thus attuned to ecologically meaningful features of their surrounds, and their ontologies are populated by, and limited to, this relevant subset. As von Uexküll puts it, the earthworm's world is made up only of earthworm things, and the dragonfly's world is composed only of dragonfly things.[3] As we shall see, this simple statement contains rich philosophical and methodological lessons for the evolution of perception and cognition.

According to von Uexküll, brainless animals are limited to reacting to relatively simple sensory inputs, whereas more behaviorally sophisticated animals are capable of synthesizing numerous aspects of the stimulus field in their central nervous system and directing motor movements in a top-down way. Thus, he says, "when a dog runs, the animal moves its legs—when a sea urchin moves, the legs move the animal."[4] He describes the sea urchin and other critters lacking a central nervous system as a "republic of reflexes" in which goal-directed behavior is built into the body plan itself. A qualitatively different kind of Umwelt arises with the capacity for object recognition, which involves integrating numerous stimuli into a single, holistic representation. In the next section, we will see how information integration is crucial not only for complex forms of representation but also perhaps for the emergence of phenomenal consciousness. But perhaps the chief contribution of Umwelt theory to modern biology has been to evolutionarily informed theories of cognition. The Umwelt lays the groundwork for a fruitful research strategy in comparative cognition: if we are to understand an animal's behavior, we should attempt to see the world through its eyes (so to speak), or as interpreted through its interconnected suite of sensory, nervous, cognitive, and motor systems.

However, there are serious problems with the original Umwelt theory that must be addressed if the concept is to prove useful in a modern biotheoretic context. These problems come from essentially three sources. The first is von Uexküll's general nonengagement with, or even outright rejection of, the two central contributions of Darwinian theory: the inference of common ancestry and natural selection as a mechanistic explanation of adaptive match. As conceived by von Uexküll, the Umwelt presupposes the immutability of species, as well as a perfect harmony between organism and environment that is permanently recalcitrant to mechanistic explanation. The dismissal of Darwinian principles, for reasons we shall see, significantly limits the explanatory power of the original Umwelt theory.

A second and related problem with the "Umwelt" as it was originally conceived stems from its entrenchment in transcendental Kantian metaphysics and epistemology. This heavy Kantian baggage leads von Uexküll not only to disregard the possibility of mechanistic explanations of biological teleology, but also to postulate mysterious vital forces that present in the form of a "Bauplan" (body plan). On his view, *Baupläne*—or, more precisely, the inscrutable forces that we attempt to reconstruct in the form of a Bauplan model—guide the teleological unfolding of an organism–environment match. Some of the reluctance to embrace the Gouldian notion of internal constraint comes from Gould's attempt to reinvigorate the scientific study of the Bauplan while jettisoning its vitalistic connotations. In its original von Uexküllian formulation, the Bauplan is unabashedly vitalistic, antimechanistic, and nonevolutionary. Von Uexküll's commitment to Kantian metaphysics also has the odd (and unhelpful) result that meaning organs do not provide information about the external environment because the external world remains permanently unknowable. Hence there is no meaningful sense in which sensory-nervous systems can be said to generate information or representational content that can be acted upon by the organism. For von Uexküll, the surrounding world is part of the animal itself.

A third source of difficulty for original Umwelt theory is its self-defeating rejection of animal psychology (*Tierpsychologie*). Von Uexküll forwent psychological categories like memory, perception, and representation, as well as attributions of subjective experience—all of which he deemed objectionably anthropomorphic as applied to nonhuman animals. This has the strange and counterintuitive consequence that von Uexküll's inner world is a purely "physiological" notion for all animals other than humans. On this view, the inner world of animals is unmediated by cognitive processes and hence is "dark" through and through, even if a central nervous system is critical to producing an appropriate behavioral response in the "effector organs." By today's lights, and indeed by the lights of von Uexküll's time (compare, for instance, his view to that of his continental contemporaries like Konrad Lorenz and Nikolaas Tinbergen), it is hard to imagine successful explanations of many animal behaviors without adverting to distinctively cognitive categories. Thus, as students of von Uexküll have been quick to point out, his third-personal model of the inner world of animals cannot plausibly be construed as a purely physiological or behavioral notion, despite his proclamations to that effect.[5]

A final feature of Umwelt theory that many contemporary evolutionists should be reluctant to take on board is its very expansive notion of biosemiotics, or a theory of signs in the living world. I suspect that most biological theorists would take the position that although "meaning"—or what we might now call "information"—is pervasive in an organism's world (and more richly present for some than it is for others), not all information should be thought of as a "signal" or "sign" properly conceived. A more restrictive but still broad-based account of biological signs, such as that proposed by philosopher Peter Godfrey-Smith,[6] might pick out the coevolution of sign production and interpretation as occurs in cases of mimicry, costly signals, and other forms of signaling that carry semantic (rather than merely causal) information.

Although the field of biosemiotics has made a comeback as of late, it has yet to formulate empirically tractable hypotheses, and some of it is as epistemically impenetrable as Kant's "thing-in-itself." To the extent that modern biosemiotics offers a cogent theory, it may plausibly be assimilated into more rigorously developed information-theoretic and teleosemantic frameworks. Biosemiotics has largely spurned information theory because of what it rightfully perceives as the inability of causal or correlational accounts of information to adequately capture the "normativity" of biological representation. Umweltian objects do seem to carry semantic information in a way that reliably co-occurring physical variables, which carry mere causal information, do not. However, there has been a recent wave of attempts to ground the "aboutness" of biological information in evolutionary function,[7] and this may be the more natural move, given that teleosemantic accounts of cognitive content are well-developed and widely deployed in biological and cognitive science.

Problems with the original conception of the Umwelt are analyzed in depth by Carlo Brentari in his impressive historical and philosophical treatment of the concept,[8] as well as by Morten Tønnessen in his own work on the topic.[9] I shall not explore these problems further. Instead, my aim will be to extract a thoroughly evolutionary, psychological, and phenomenological conception of the Umwelt that can be more readily assimilated into our contemporary scientific understanding of the living world. On this account, Umwelten, like other complex traits of the organism, are shaped by natural selection, and natural selection is guided in part by the objective structure of the external world. From a contemporary evolutionary perspective, we have strong reasons to think that perception is largely a veridical, truth-tracking process. As theoretical biologist Stanley Salthe, who is otherwise sympathetic to biosemiotics, points out, the material reality that lies beyond (and behind) Umweltian objects is a purveyor of true signs, lest the Umwelt never evolve at all.[10]

Recognizing that there are both internal and external constraints on the shape of Umwelten can go some ways toward explaining why Umweltian ontologies are "filtered" in the ways that they are, and why in other respects—such as with regard to the common core of consciousness—they are deeply convergent. Umwelten will vary as a function of the ISMs that lineages possess and the particular subset of environmental signals that a lineage has evolved to detect, interpret, represent, attach affective markers to, and act upon. Because only a subset of available information will be useful to an organism, natural selection will ensure that the lion's share of an organism's perceptual and cognitive resources is devoted to processing information that *matters*. The Umwelt will thus employ adaptive filters that sift informational environments for meaning; and the more information that a lineage can process, package, and act upon, the richer and more meaningful its Umwelt becomes.

Von Uexküll, for his part, was loathe to cede causal powers of the organism to the environment, for he feared that doing so would be to surrender to an environmental determinism of development (recall that Von Uexküll's account is developmental, not evolutionary). Yet we can acknowledge that the external environment shapes perception and cognition in meaningful ways without presupposing any sort of environmental determinism for ontogeny, and without rejecting the idea that organisms actively construct inner models of the external world rather than passively perceive their surrounds. Acknowledging that features of the external world constrain adaptive evolution, including the evolution of the Umwelt, does not commit us to an objectionably strong "externalism" about selection or to what Lewontin has critically dubbed the "lock and key" model of adaptation.

The final bit of von Uexküllian baggage that needs to be jettisoned before we can proceed unencumbered with an evolutionary notion of the Umwelt is his eschewing of psychological and phenomenological attributions in favor of exclusively physiological ones. As noted earlier, von Uexküll avoided mental concepts in characterizing the Umwelt of nonhuman animals, even those that have central nervous systems similar to our own. Yet it is impossible to make sense of the Umwelt and how it underwrites sophisticated goal-oriented behavior without adverting to distinctively cognitive categories, such as representation, memory, and other forms of information packaging and processing. In addition, subjective experience—actually, *subjectivity of a specific sort*—is also built into the deep structure of the Umwelt. Or so I will argue.

2.2 *Sentio Ergo Sum*

What do sunsets, symphonies, sewage, and sadness all have in common? They each have a unique experiential quality that cannot be captured, perhaps even in principle, by third-personal descriptions, no matter how complete these descriptions might be. To trot out the standard primate-centered example, even a complete understanding of the neurocognitive mechanisms that give rise to our experience of the redness of a sunset would not give us access to the experience of redness itself—they would not tell us, as the philosopher Tom Nagel famously put it, "what it's like" to see red.[11] The central task of the science of consciousness, according to philosopher David Chalmers, is to relate and integrate these first-personal (internalist) and third-personal (externalist) perspectives on the world.[12] The Umwelt construct, as conceived here, spans this internalist–externalist divide.

The inner world of subjective experience may not only be epistemically impenetrable to external observers, it may also be epistemically privileged among sources of knowledge available to the subject. Descartes's famous insight *cogito ergo sum* (canonically formulated, "I think therefore I am") can be modified to make an equally foundational epistemological claim about experience: I know first and foremost that I am an *experiencing* thing. Whether these experiences correspond to features of the world is a secondary question, and one that can never be answered as self-evidently, or with as great a certainty, as the first. As psychologist William James noted, what we conclude from introspection is not that experiences exist out there in the world, but rather that these experiences are *our own*. Some of these experiences involve thinking in the rich Cartesian sense, but many, perhaps most, involve brute perceptions of the world. These perceptions may not be veridical: I could be dreaming, delusional, or a virtual cog in a grand electronic simulation run by superintelligent aliens, and yet the bare fact that I am an experiencing thing is unassailable.

I may attribute similar conscious states to other similarly situated beings—and the better part of the next two chapters will be spent fleshing out what "similarly situated" here might mean. But any such third-personal attributions will be grounded in empirical *inferences*, not self-evident propositions. My own existence as a subject of experience would seem to entail the existence of an appropriately configured physical substrate, such as a brain, out of which my subjectivity emerges. But this, too, is not an epistemically self-evident proposition, but rather an inference made on the basis of third-personal observations of the causal relations between behaviors (including conscious reports) and brain states.

Importantly, we can accept the central Cartesian insight about subjective experience without signing on to Descartes's metaphysical commitment to "substance dualism"—the notion that mind and body are composed of distinct substances—or to his claim that the mind can outlive the body. We now know from careful studies of anesthesia and brain-damaged patients that subjective experience is intimately connected to brain activity and, in particular, to brain activity in specific regions of the brain. We know, for instance, that damage to certain functional brain areas, such as the cerebellum, does not affect consciousness, whereas lesions to other brain areas, such as the cortex, can have profound, content-specific effects on consciousness and its character. Other neurological structures, like the reticular formation of the brain stem, appear to be crucial for conscious activity but do not influence the specific contents of conscious experience. It is also clear that consciousness can be present in varying degrees in the same human subject, depending on the subject's underlying brain activity: we are more fully conscious while downhill skiing and less so when we are asleep or under a twilight anesthesia. And even though sensory inputs influence the content of conscious, conscious states can be present despite the complete absence of sensory inputs, as in the case of dreams.

At the same time, consciousness does not seem to be *equivalent* to any brain states or processes. Neurocognitive functions could in theory be described completely and entirely in mechanistic (or processual) terms without any reference to experience. Furthermore, we can logically conceive of a being that possesses all of the same brain and behavioral states that we have but nevertheless lacks the subjective qualities that, in our nomic universe, accompany them. The logical possibility of philosophical "zombies," as such beings are called, is one of many arguments intended to establish "property dualism" about mind, according to which conscious states are not identical to brain states. Property dualism rejects Cartesian dualism insofar as it accepts that conscious minds cannot exist without brains (or some functionally equivalent material realization base), but it maintains that states of subjective experience are not identical to states of the brain. On this view, the ontology of mind is not coextensive with the ontology of the brain, even if the former "supervenes" on the latter. Some theorists subscribe to Marvin Minsky's view that "minds are simply what brains do"; but on the property dualist view, one thing that minds do is generate conscious states that are not equivalent to brain states.

The deep mystery of consciousness is thus threefold. First, why is the internal perspective of subjective experience epistemically inaccessible to external observers? Second, why should brain states feel like anything at all to the embodied system? And third, why do particular instances of consciousness have the contentful qualities that they do? Why, for example, is our experience of blueness not like our experience of redness or, for that matter, like our experience of the rising sound of a malleted gong?

It could be that phenomenal consciousness is simply a brute set of necessary relations that can adequately be described but not explained in mechanistic terms. It could also be that in the future, consciousness will be shown to reduce to physical states or be exposed as an artifact of asking the wrong questions. I have no decisive sense of which view is more likely to be right. I wake to find myself skeptical of philosophical pronouncements of in-principle limitations of third-personal explanation; but by the end of the day I become convinced that the problem of subjective experience is a profound one, leaving me to suspect that consciousness may be built into the fabric of the universe.

This chapter will ultimately give the Umwelt an experiential gloss. However, we can understand the evolution of Umwelten and how they transformed cognition, behavior, and ecology without making any conscious commitments, so to speak. That is to say, we can talk about how independent lineages of animals came to represent the world as a unified field of discrete, spatiotemporally distributed, property-bound objects with a representation of the self (loosely conceived[13]) at the center of this field—and we can begin to sketch how this cognitive innovation spurred further behavioral, anatomical, and neurological evolution—all with nary a mention of the 500-pound gorilla in the room: subjective experience.

And yet this would do great epistemic injustice to the gorilla. We do not know *why* we are conscious, but we know, perhaps above all else, *that* we are.

The third-personal inference from our own subjective experience to the existence of other subjective experiencers seems if not self-evident, then unproblematic. Why should the laws of nature be different for me than for other nearly identically configured beings whose behavior is remarkably similar to my own? When it comes to many nonhuman animals, however, this inference enters choppier epistemic waters. It is an open question whether nonhuman animals, which differ to varying degrees both neuroanatomically and behaviorally from human beings, are suitably configured for conscious experience. Similar inferential problems arise in relation to less metaphysically problematic mental categories, such as cognitive mechanisms, which also cannot be directly observed.

Some theorists, going back to Descartes, have argued that consciousness did not spring into being until the origin of language and its attendant capacities for symbolism and logical recursion. However, there is neuroscientific evidence that subjectivity (phenomenal consciousness) can be physically disassociated from both self-awareness and linguistic capacities. The latter two higher-level properties are linked to functions of the cortex, whereas subjectivity appears to be generated by more evolutionarily primitive areas of the midbrain—a finding that is consistent with so-called "first-order" representational theories of consciousness.[14] Thus, humans can be phenomenally conscious even when their cortical functions are blocked. There is, moreover, nothing inherent to linguistic capacities that would suggest they are a precondition for bare bones subjectivity, or even for subjectivity of the sort that we experience during much of our waking (and dreaming) lives. The strong language-subjectivity link thesis would imply, for example, that if archaic *Homo sapiens* lacked language and other symbolic recursive abilities, then they were mere zombie automata—a most implausible result.

It seems far more likely that language and other recursive or metacognitive additions to the mental repertoire added additional layers of phenomenal quality on top of a more basic platform of subjectivity. This view jibes with a distinction drawn by some leading researchers of consciousness, such as David Edelman and his collaborators, between "primary consciousness"—defined as the ability to construct a unified, multimodal phenomenal scene—and "higher-order consciousness"—defined as the ability to recall past scenes and project future scenes and to have a narrativistic mental representation of self.[15]

The claim that consciousness arose in tandem with language is plausible only if "consciousness" is taken to refer to something very cognitively rich—such as the awareness of self (in a thick sense) or some other meta-representational ability picked out by higher-order theories of consciousness.[16] Even this more limited claim may be a stretch, however, given that a number of animals appear to be self-aware and yet lack natural language abilities. Because our best operational measures of self-awareness, such as the mirror self-recognition test, are met by a wide range of animals that are not natural (or even artificial) language users, this suggests that the link between language and consciousness-as-self-awareness is tenuous at best.

The restrictive view that phenomenal consciousness arose in the most recent eye blink of a >600 million-year history of animal evolution can be contrasted with maximally promiscuous views, such as panpsychism and biopsychism, which hold that mind is in all matter and in all living things, respectively. The position advanced here is that consciousness in any meaningful form did not arise until the emergence of the Umwelt, an event that occurred several times independently in the early phases of animal evolution (see chapters 9 and 10). The qualification "in any meaningful form" is intended to leave open the question of proto-subjectivity in non-Umweltian life: for instance, whether there is "something it feels like" to be a brainless multicellular or unicellular organism, even if that feeling is very minimal. As Peter Godfrey-Smith has noted, the difficulty with extreme continuity views such as biopsychism lies in "thinking about the difference between a complete absence of subjective experience and a minimal but nonzero scrap of it."[17] This difficulty compels Godfrey-Smith to reintroduce an older distinction between qualia and consciousness, wherein "consciousness" refers to a thicker, richer notion of subjective experience while "qualia" refers to a diffuse feeling that need not be associated with any particular form of cognition.

Similar work is done here by the Umwelt, which in broad strokes describes the kind of consciousness with which we are intimately acquainted—a form of experience that we can, in effect, imagine. Drawing inferences about the phylogenetic distribution of Umweltian consciousness requires that we commit to substantive claims about (1) what conscious experience consists in, (2) how it is related to brain structure and functionality, and (3) how it is reflected, if at all, in measurable neuroanatomical and behavioral data. In the remainder of this chapter, we will tangle with the first two elements of this problem, and the next two chapters will wrestle with the last.

3. The Umwelt Experience

Meaning in the universe arises not with the origins of life *simplicter*, but with the origins of *conscious* life. Meaning is *felt*, not merely represented. A universe teeming with zombie animals, though rich in representation, would be bankrupt of meaning. Is consciousness a freak accident of earthly evolution, or is there a law-like necessity to the way in which, as David Edelman and

Giulio Tononi elegantly put it, "matter becomes imagination"?[18] How can we determine whether the light of consciousness is part of the nomic structure of the universe?

Here again we are encumbered by an observer selection bias. Any being contemplating the contingency of consciousness must necessarily hail from a planet, and from a universe more broadly, in which consciousness arose at least once. All we are permitted to conclude from the existence of our own mind is that consciousness is *not prohibited* by the laws that govern our universe; this tells us nothing, however, about the frequency distribution of consciousness across the cosmos. Once again, convergence offers a way out of this epistemic quandary: any observer contemplating the contingency of consciousness need not hail from a history of life in which consciousness arose *multiple times*.

In order to identify evolutionary replications of consciousness, we must first establish the distribution of consciousness in the tree of life. Before we can do that, however, we must address several big ticket philosophical questions. First, what is phenomenal consciousness, what brain functions are implicated in subjective experience, and how is consciousness related to cognition in general and Umweltian cognition in particular? Second, how can we make sense of the notion that phenomenal consciousness admits of degrees in richness or complexity? An answer to the latter question will prove important if consciousness, like cognition, turns out to be a basal animal trait with a continuous ontological distribution. Finally, what do our answers to these questions reveal about the adaptive function of consciousness or its underlying substrate?

3.1 The Evolutionary Replicability of Cognition

Let us begin by considering the relation between consciousness and cognition. On the view defended here, cognition is a broader phenomenon than consciousness, in that only some cognitive functions generate, or are associated with, subjective experience, but no subjective experience can exist in the absence of cognition. What then is cognition, and do we have reason to think that it is a universally projectible feature of living worlds?

As with evolutionary outcomes in general (see part I), the extent to which cognition is evolutionarily replicable will depend in part on how the trait is described. For example, if we presuppose an account that conceives of cognition not merely *in terms of* information processing, but *as* mere information processing,[19] then it will encompass the quite sophisticated information processing and attendant behavioral-response capacities of plants.[20] Indeed, on such inclusive accounts, prokaryotes and other unicellular microbes, and perhaps all lifeforms of any appreciable complexity, could be said to exhibit minimal cognition. This is because cognition will be instantiated in bare metabolic and reproductive processes, and because metabolism and replication are probably universal features of life in the universe, this would imply that cognition is a universal feature of life as well. Homeostatic mechanisms, for example, involve processing and responding to information about internal and external states of the organism in order to maintain energetic nonequilibrium (i.e., to avoid death). As Godfrey-Smith has explained, metabolism actually entails quite a bit more than information processing; it involves sensing and responding to the world (such as via gene-regulation) in order to maintain the integrity of the organism.[21] As a result, metabolic capacities may be thought of as "proto-cognitive."

Other more restrictive but still biologically broad-based accounts aim to more cleanly distinguish minimal cognition from metabolism. They do this, for example, by holding that minimal cognition consists in sensorimotor mechanisms that are decoupled from metabolic processes and thus support faster information flows—a function that is paradigmatically realized by nervous systems. Yet even on these accounts there are functionally analogous molecular signaling systems in plants, in unicellular eukaryotes, and even in bacteria—all of which exhibit functional analogs to memory and learning that are decoupled from metabolism.[22] Brainless organisms, and even organism without neurons, have been shown to possess molecular signaling mechanisms that are designed specifically for information transfer.[23] Thus, even the "sensory-motor" account of cognition is not limited to organisms with brains and can be expected to be a universal feature of life.

Notice that on these big-tent accounts, there is nothing inherently *mental* about cognition. Thus, cognitive capacities broadly conceived are not sufficient for the emergence of experience in anything like the Umweltian sense. The Umwelt requires specialized modes of information processing and integration that are only realized in suitably configured brains.

3.2 Information and Integration

To understand how information processing centers might be configured for consciousness, we will help ourselves to the work of theoretical neuroscientist Giulio Tononi and his collaborators.[24] In a series of papers that are as stunning in their clarity as they are impressive in their quantitative rigor, Tononi argues that conscious experience consists of the integration of information, and he provides a theoretical framework for measuring this property. Although there are many working definitions of consciousness on offer in the literature, Tononi's account dovetails with the kind of information processing capacities that underpin the Umwelt. It also helps to explain how richer forms of experience might arise from more basal, simpler forms of subjectivity over the course of evolution.

Unlike many neuroscientists and some skeptical philosophers, Tononi takes consciousness—first-personal subjectivity—as a central explanandum of mind science. He presents the problem of consciousness and motivates a solution by way of several key thought experiments. In the first, he invites us to consider a photodiode, or a simple light-sensitive device, placed in front of a screen; the photodiode is set up to either initiate a beep when the screen lights up or to remain silent when the screen is dark. A human observer can be asked to perform the same task as the photodiode, but in the human case the observer "sees" the screen light up whereas the photodiode presumably has no such experience.

According to Tononi's integrated information theory of consciousness (IIT), there are two key differences between the human and photodiode systems that result in conscious experience in the first case but not in the second. The first difference concerns the sheer amount of information that is generated. On classic interpretations of information, information just is the reduction of uncertainty in an unpredictable world.[25] Unpredictable worlds are worlds in which there are many possible outcomes, moment to moment, with more or less equal probabilities. For instance, in unpredictable environments, whether a particular light, shape, color, conspecific, predator, foraging item, obstacle, chemical gradient, or danger is present in the surrounding environment may be more or less a crapshoot. The more alternative possible outcomes that a system can detect, the more it is capable of reducing uncertainty and thus the more information that it generates or processes. When a human registers the screen light up, the observed state is one of a vast number of possible alternative states of light, color, shape, duration, or motion corresponding to a vast amount of information. In contrast, for the photodiode, the detection possibility space is maximally depauperate: the system either detects or fails to detect a single state.

Now modify Tononi's thought experiment to include a photodiode that is set up so that it initiates a beep only when light waves in the blue spectrum are detected. The result would presumably be the same as the simple photodiode described above: there is no sense in which the quale "blue" would be generated or experienced by this binary detection system. The ability of a system to detect blue-wavelength light is clearly not a sufficient condition for generating the quale blue, nor for that matter any qualia at all. Why might this be so? One reason may be that there is no contrasting set of color possibilities—no informational color space, as it were—with respect to which the discrimination "blue" could be made.

A biological analog to the photodiode set up to detect a narrow band of electromagnetic radiation is the thermal imaging organs of pit viper snakes.

Pit vipers have a series of deep pits on each side of their head that are packed with cells that are highly sensitive to infrared wavelength light (or heat). The pits, which essentially act as lensless eyes that allow the snake to detect the heat signatures of prey and predators, are capable of detecting heat differentials as small as 0.01°C. Whether there are any visual qualia associated with these organs—whether there is something it is like for pit vipers to see heat—depends not merely on detection but also and crucially on what is done with that information after detection. In particular, it depends on whether and how that information is integrated into other aspects of the pit viper's visual scene. Given that thermal pits lack lenses, it is likely that infrared light is not bound into visual objects of the pit viper's Umwelt. Precisely what it feels like for the pit viper to sense heat, if it feels like anything at all, is unclear.

Further lessons about the nature of visual qualia can be gleaned from rare but revealing brain disorders in humans. The neuroscientist Oliver Sacks recounts that patients with total cerebral achromatopsia—the complete loss of color vision—report that they do not experience a world in shades of grey, as one might expect under such limited sensory conditions.[26] Rather, they report that their deficit is more fundamental and indescribable. This suggests that our experience of grey depends on the informational color space that is available to us. If this is right, then perhaps it is wrong to say that my Australian Shepherd, who has dichromatic (blue-yellow) vision, sees the red outline of her beloved flying disc as "brown." And perhaps bees experience colors differently than we do because they have an expanded repertoire of color perception that includes ultraviolet light which paints tiny landing pads on nectar-bearing flowers.

What if instead we set up a photodiode system so that it lights up red if light of red wavelengths is detected, blue if light of blue wavelengths is detected, green if light of green wavelengths is detected, and so on down the spectrum. Does this more informationally discriminating system have experiences of color? Though more sophisticated, the discrimination is still discrete, whereas colors are experienced as having continuous or spectral qualities. But suppose that we configure a more sophisticated photodiode array so that it can detect nuanced spectral differences in visible light arranged in virtually an unlimited number of spatial combinations, thereby generating vastly more information than the binary photodiode. Does this informational complexity endow the system with the experience of color?

Tononi considers just such a system—a digital camera—in order to show that subjective experience does not fall out of information processing alone. He replaces the photodiode in his thought experiment with a digital camera that comprises over 1 million photodiodes and hence can record a vast number of possible configurations of the world. Even though the camera system can process a huge amount of information, there is probably nothing it is like to be the camera—no private first-personal perspective, no inner camera world. Why is this so?

Tononi's answer is that the camera is a collection of low-information photodiodes that is decomposable into its elements, not an integrated system where the actions of one component are causally related to the actions of another component. In contrast, in human brains, a vast amount of information is not only generated but also *integrated*, with the states of some nervous system components influenced by the states of others at global scales. Integration is realized in nervous systems by virtue of what Gerald Edelman dubbed "reentry": recursive interchanges or coordinated mutual stimulations of dispersed neuronal groups. In ways that are poorly understood, reentry allows information to be packaged—and thus experienced—in more complex forms, as exemplified by the bound object percepts that crowd the Umwelt experience.

The full spectrum photodiode is just as much of an automaton as the binary photodiode, even though it processes vastly more information. More important than the total quantity of information processed by a system is how that information is packaged and combined with other bits and made available to the wider system. Why should we think that information integration is crucial for conscious experience? Tononi argues that the strongest evidence for the role of integration in consciousness comes from the phenomenological unity of consciousness. Consciousness cannot be parsed or decomposed into separate experiences of shape, color, motion, or space, even though these features are processed by different specialized brain areas dispersed throughout the cortex. As far as we can tell, there is no common cortical area where integration takes place, yet somehow properties are integrated or "bound" into unified object percepts (see section 3), which in turn are woven into the phenomenal fabric of the Umwelt.

Earlier we spoke of the Umwelt as a unified model of the external world that is "presented" to the subject. This characterization might seem to presuppose the existence of what Daniel Dennett has derisively called the "Cartesian Theater"—the intuitive but empirically unsupported notion that there must be a physical location in the brain where it all comes together and percepts are presented to the conscious subject. Yet as Dennett points out, the Cartesian theater leads to an infinite regress of homuncular minds: an infinite, nested set of experiencers within experiencers, with no explanatory purchase to be had. Several decades of neuroscientific research support Dennett's contention that there is no physical place in the brain where it all comes together. It does not follow from this, however, that the unity of conscious experience is itself an illusion. We know with great certainty that it does all come together *for the* *perceiver*. And this phenomenal coming together is a central feature of consciousness as we understand it. The coordinated firing of dispersed neuronal subsystems is likely to play a crucial role in this unifying process, but most of the integration story remains to be told.

Somewhat harder to situate within the Tononian framework is the nontrivial amount of integration that goes on in the cortex outside of conscious awareness (such as in certain streams of visual processing), which could lead one to question whether integration is in fact sufficient for subjective experience. Perhaps these subsystems are weakly and privately conscious in ways that we cannot assess or comprehend; or perhaps they are miniature zombies that simply feed information into the larger conscious system that we identify with and report on. At the most minimally conceivable level, perhaps there is something it is like to be two integrated neurons.[27] It is hard to know how we could adjudicate these questions, given that these modules are not wired-up for consciousness-indicative behaviors.

Tononi's response to the "nested experiencers" problem, it seems, is to argue that only *maximally* integrated information structures are the loci of subjective experience. On this view, there is nothing it is like to be the internet, or, presumably, an ant colony; although these systems exhibit minimal integration, they contain maximally integrated loci within them (e.g., individual ants) that effectively divide or decompose any subjective experience that might exist at the level of the whole. On this view, damage to subsystems that are weakly integrated with the main system, such as "encapsulated" modules, may affect the quality or richness of conscious experience (as with patients who have lost partial color vision), but these subsystems do not themselves give rise to subjective experience—they simply feed into the main system that does. This is the case for structures like the brain stem and cerebellum as well as for sensory input apparatuses (like the retina) and behavioral output devices (like the motor system) that stream information into or out of the main system.

If this is right, it would explain why a severed corpus callosum (mentioned earlier) results in the collapse of a single unified subject into two separate independently embodied loci of experience, but no more.[28] Yet even if patients with a severed corpus callosum are in fact harboring two distinct loci of experience, this does not show that they or individuals with normal brains do not harbor many more experiencers within them, because the behaviors and reports elicited in experiments do not speak to that question. As Thomas Nagel points out in one of the first philosophical treatments of the split-brain phenomenon,[29] there is no reason to think that verbalizability, or, we might add, any motor output capacity, is a necessary condition for subjective experience. Because measurable outputs will generally occur at the level of maximal integration—

that is, at the level of the organism as a whole—they say rather little about the presence of subjective experience in subsystems that are nested within the main system, whether these subsystems are neuronal networks or even neurons themselves. The notion of nested experiencers may be counterintuitive, but if we have learned any lesson from modern science, it is that the range of things that exist and the range of things that are intuitively plausible often fail to overlap. It is probably best, therefore, to remain agnostic as to whether there are nested experiencers within maximally integrated conscious systems.

Thankfully, the explanatory aims of the present project permit us to avoid taking a stand on the question of nested experiencers within a single animal. Our goal here is to zero in on the evolutionary function of Umweltian consciousness by linking it (or its neurocognitive generators) to more sophisticated forms of adaptive behavior. Because the evolutionary functions of traits are generally assessed at the level of the organism, we can safely elide the question of nested experiencers whose functions are causally screened off by the maximally integrated information structures that power the behavior of organisms upon which selection can act. Informational integration at the organismic level is therefore the appropriate level of analysis for the present study, whether or not it exhausts the universe of subjective experience.

Tononi insists that phenomenal consciousness just is the integration of information as expressed in mathematical terms. On his view, phenomenal states are metaphysically identical to integrative informational states. And if experiences just are maximally integrated information structures, then experiences cannot be said to *arise from* these structures. Conceived in this way, information integration is not a correlate, generator, or signature of consciousness, but rather what consciousness consists in. Edelman and Tononi thus claim to solve the first-personal/third-personal explanatory divide,[30] but they do so by essentially defining the problem away: consciousness just is informational integration.

Nevertheless, it is clear that the IIT does not solve what Chalmers understatedly called the "hard problem" of consciousness: the challenge of explaining why integrated informational processes, or for that matter any functional cognitive architectures, should generate private experiences at all, and why these experiences are only accessible from the inside. If we can reasonably ask whether integrative informational structures do or do not generate subjective experiences, then this suggests that informational structures are not metaphysically identical to conscious states, even if they are nomically linked to them. In fact, the IIT can be *glossed entirely in third-personal terms*. That is, it could characterize integrated information structures in a way that successfully explains cognition and behavior without making any reference whatsoever to subjective experience. If this is right, then the subjectivity element does no explanatory work in the model—and this lack of explanatory work is precisely what compels some leading philosophers of mind to defend an epiphenomenalism about consciousness.

3.3 The Binding Problem(s)

The role of informational integration is perhaps most salient in the case of binding. The "binding problem" refers to the puzzle of how sensory information about different features of objects (such as shape, color, and motion), which are processed in different specialized regions of the brain, are somehow integrated or brought together to form the array of complex object percepts that make up the Umweltian scene. In fact, there are two distinct versions of the binding problem. There is the binding problem in cognitive neuroscience, which is addressed to a representational puzzle; and there is the binding problem of subjective experience, which is addressed to the unity of consciousness.

The first problem is entirely third-personal and queries the neural mechanisms through which objects are "bound" with a constellation of properties that move with them over space and time. Redness and roundness, for instance, are properties that are bound to the apple and travel with it as it retains its perceived identity across temporal frames. There has been much work in cognitive neuroscience attempting to understand the mechanisms that are used to carve up the world of objects at its joints. The cognitive psychologist Anne Treisman provides a typology of binding according to which objects are bound *in properties* (such as color, shape, and motion); objects are bound *in space* (placed in specific locations) and object properties are spatially localized within objects; objects are bound *in time* such that they are recognized as the same object at different temporal intervals, even though they assume different orientations and occupy different locations in a cluttered scene; and objects are bound *in their parts* such that all of their parts are recognized as features of the same object, which "pops" out of the visual scene. Although such representations are imagistic, they are not purely "iconic" (in the technical sense that different aspects of the representation correspond to different aspects of the object or scene); additional representational formats are required for objects bound with numerous features to pop out and maintain a permanent identity over space and time.[31] This "temporal thickness" of cognition, as Zohar Bronfman and colleagues call it,[32] is the basis of working memory and figures into sophisticated goal-oriented behavior (see chapter 10).

We can add to this typology of binding the notion that objects are bound *in meaning*: that is, they are seen "as an obstacle" or "as food" or "as a predator" or "as noise"—categorizations that are attended by corresponding affective valences (positive, negative, or neutral) encouraging adaptive approach, avoidance, or ignoring behaviors. Some valences attached to complexly bound objects or action sequences may be innately specified while many others will be learned through experience via mechanisms of associative learning. When meaning is attached to a bound representation through categorization and the attachment of an affective marker, this amounts to "semantic-conceptual binding," as philosopher Antti Revonsuo calls it.[33]

One reason to think that different aspects of binding are handled by distinct subsystems of the brain is that different "agnosias," or sensory deficits caused by brain damage, are associated with specific binding failures. Oliver Sacks offers striking depictions of patients who are unable to bind colors to objects, others who can bind properties to objects but cannot bind objects to locations, and still others who can bind properties to objects and objects to locations but cannot bind meaning to objects.[34] Patients with these agnosias experience visual stimuli, but their visual experience is so fractured that they appear by their actions to be blind or incoherent. More common and less catastrophic disorders of binding include various types of synesthesia in which patients not only associate but actually experience colors in response to sounds or shapes in response to tastes.[35]

Visual stimulus binding is not the end of the sensory integration story, however. For animals that have multiple modalities, information can be integrated cross-modally so that smells and sounds are attributed to visual objects and vice versa, allowing distinct sensory systems to inform one another in working toward the best perceptual guess about states of the external world. Mundane cross-modal illusions,[36] like the ventriloquist effect, show how one sensory modality—such as a visual percept of the "chattering" ventriloquist dummy—can influence another modality—such as the perceived location of audible speech, which is erroneously bound to the marionette.

Any full-bodied solution to the binding problem must describe not only the mechanisms that underlie stimulus and semantic property binding but also the neural-cognitive generators of the final bound representation—the one that we "see" and that is made available for thinking and action. In addition, it must explain how the constellation of final bound representations are woven together into a single, unified Umweltian scene. This last aspect of the binding problem is probably the least understood. There is growing evidence that neural synchrony and reentry are both important mechanisms underlying the information integration that occurs in binding.[37] Described thusly, however, the binding problem is a wholly third-personal puzzle: it concerns how complexly integrated representations are formed in the brain and made available to memory and reasoning in order to guide action.

The relation between binding and consciousness is less clear. Neurocognitive binding surely affects the character of Umweltian consciousness and may be a necessary condition for it. Whether binding provides sufficient conditions for subjectivity in Umweltian or even more basic forms is not evident. In theory, neurocognitive binding and phenomenological binding could come apart—this would be implied, for example, by evidence that bound representations are sometimes formed outside of subjective experience. One possibility is that binding may not be sufficient for phenomenal consciousness unless it also includes affective content that projects meaning onto objects and events, thereby creating an Umweltian subject (see chapter 10 for more details). If so, then bound representations that lack affective content would fail to generate conscious experience. It could be, for instance, that bound representations are formed by the synchronous firing of distributed neural systems that specialize in different features of the scene, but that this bound representation must then be made accessible to the wider system for memory, categorization, and affective response if it is to become part of the stream of consciousness. And if this is so, then information integration would not be sufficient to generate subjectivity. Although much of this picture remains opaque, work on binding is providing the first glimpses of how the Umwelt was made.

4. Evolutionary Gateways to the Umwelt

One might argue that the best way to understand the causal structure of mind is to understand its evolution. This was perhaps Charles Darwin's deep insight when he famously jotted down in his notebook that "He who understands baboon would do more toward metaphysics than Locke."[38] Conceiving of consciousness in terms of the information integration that is implicated in the various forms of binding we have discussed renders the Umwelt an epistemically accessible target of evolutionary explanation.

4.1 Consciousness as Evolutionary Explanandum

There are two broad causal frameworks of evolutionary explanation that could account for the emergence of Umweltian experience: an adaptationist account and a by-product account. The adaptationist account takes consciousness to have causal properties that are relevant to fitness—properties that explain its origin, molding, and proliferation under the forces of natural selection. The by-product account, on the other hand, takes consciousness to be a collateral consequence—an incidental side effect—of selection for other neurocognitive properties. "Exaptationist" accounts of consciousness, meanwhile, hold that consciousness arose as a by-product of other neurocognitive adaptations but was subsequently shaped by selection for its own fitness-relevant properties. For our present purposes, exaptationist and adaptationist accounts are aligned because both attribute causal properties to subjectivity, whereas the by-product account is consistent with denying that subjectivity has any causal properties at all (though it need not entail this).

Conceived as global information integration, consciousness is not only causal, but causally predominant—for in typical cases, global integration screens off the causal inputs of modular subsystems with respect to organismic behavior. An exception is the cognitive phenomenon of "blind-sight,"[39] which shows that some behavior-affecting visual processing and attention can exist outside of conscious awareness—which, for some authors, raises the very real prospect that nonhuman animals are totally blind-sighted.[40] But if consciousness is, in general, a predominant cause of organismic behavior, then this opens the door to its having an evolutionary function; or, more precisely, it opens the door to its *being* an evolutionary function of suitably configured brains. The capacity to integrate information is presumably an evolutionary function of specialized neural anatomies, such as reentrant pathways, neuronal synchrony, and the central processing centers that serve as what theoretical neuroscientist Bernard Baars has called a "global workspace" for the flow of information, in which different modular inputs compete for the "spotlight" of selective attention.[41] As we shall see in the next two chapters, such integrative neural architectures look to be convergent across vertebrates and invertebrates, and their functions are corroborated by comparative studies of animal behavior.

Whether the adaptationist account takes consciousness-as-information-integration to be a *trait* (like the ichthyosaur dorsal fin) or the *function* of a trait (like stabilization during swimming), information-integrative structures are astronomically unlikely to have evolved by sheer accident—for they are as superbly matched to complex cognitive tasks like binding as ichthyosaur fins are to swimming at speed. And just as the convergent evolution of dorsal fins in fish, ichthyosaurs, and dolphins is indicative of external constraints on form, so too is deep convergence on information-integrative architectures evidence of external constraints on cognition that transcend the body plans of the particular animal groups in which they are found.

Alternatively, one might want to resist Tononi's stipulation that consciousness equals information integration. In this case, one might hold that integrated informational structures are the function of the adaptive neurocognitive configurations mentioned earlier but that consciousness itself is a by-product of selection for that function. On this by-product view, first-personal perspectives arise under the nomic conditions approximated by IIT (or some other successful third-personal theory), but they are not equivalent to those conditions. The by-product theorist might further insist that consciousness is a *noncausal* side effect, in that it exerts no influences on any events (neurocognitive or behavioral) that could be "seen" by natural selection. For present purposes, we can remain neutral as to whether the adaptationist or by-product account of consciousness is more plausible. Although each view conceives of the nature of consciousness very differently, both take the gorilla seriously as a legitimate target of evolutionary explanation.

With consciousness now firmly within the ambit of evolutionary explanation, let us consider how ISMs are connected to the origins and character of subjective experience. If a broadly biopsychist account of mind is correct, then minimal subjectivity would have preceded the evolution of the Umwelt, even if we have little imaginative sense of what minimal subjectivity might feel like. But consciousness *as we know it*—the construction of an Umweltian scene with the subject of experience at the center—arose only with the evolution of centralized brains and the informational integrative functions they achieved. The evolution of centralized brains, in turn, arose in coevolutionary feedback with ISMs as well as motor and proprioceptive systems, with the ISM and embodied Umwelt elements of a single, law-like coevolutionary package. As primitive ISMs increased in resolution and provided access to vastly more information, the nervous systems of ISM-bearing lineages underwent selection for neurocognitive architectures that could bundle that information into more complex, bound representations, which in turn could be made available for decision making and action.

Binding is implicated in the two types of phenomenological unification that form the Umwelt: local unification, in the form of bound object percepts, and global unification, in the form of a seamless panoramic field of objects with the subject at the center. Each of these types of unification increase situational awareness, or the simultaneous tracking of numerous bound features of the environment, in order to guide the organism in real time through a complex, three-dimensional, and meaningful world. Information about nonimagistic (e.g., olfactory, auditory) stimuli can be integrated into and inform the construction of the phenomenal scene, but it is properly imagistic perception afforded by an embodied ISM that renders the Umwelt.

4.2 Phenomenology of the ISM

What are the physical, cognitive, and phenomenological features that make a sensory modality an ISM? In chapter 7, we saw that vision, echolocation, and electrolocation all permit holistic object recognition and the construction of a unified phenomenal scene. One justification for this typology of "seeing" is cognitive: what makes these sensory modalities types of ISM, notwithstanding their very different energetic bases (electromagnetic radiation, sound, and electromagnetism, respectively), is their representational contents—the features of the world that they represent. These features include things like shape, texture, color, motion, and relative position, which are bound (along with affective valences) into spatiotemporally differentiated objects that are in turn integrated into a meaningful Umweltian scene. Add to this the not implausible assumption that the character of experience is roughly determined by representational content—such that there can be no change in phenomenal character without a change in representational content, and such that many if not all changes in representational content will result in changes in phenomenal character. It follows that since ISMs overlap to a significant degree in representational content, they also overlap to a significant degree in the character of experience. Thus, both cognitive and phenomenological similarities point to a common sensory system type: the ISM.

Alternative ISMs, such as echolocation and electrolocation, are representationally and experientially more like vision—which exploits a different waveform energy—than they are like other sensory modalities that use the same waveform energetics and homologous sensory components but differ greatly in their representational and phenomenal content. For example, vision is more like echolocation and electrolocation than it is like phototaxis or heat sensing, even though vision exploits light and uses photoreceptors; echolocation is more like vision and electrolocation than it is like audition, even though it exploits sound and uses the ear; and electrolocation is more like echolocation and vision than it is like magnetoreception, even though it exploits electromagnetic fields and uses electroreceptors. Another way of putting the point is that if we were able to construct a "sensory system phase space" along representational and experiential dimensions, then ISMs would all be closer to one another in that map than they would be to other modalities like phototaxis, heat sensing, magnetoreception, and audition.[42] Nagel may be right that we can never know what it is like to be a bat without being bat-embodied; but however alien the phenomenology of the echoic scene might be, the bat Umwelt is a coherent way of relating to the world, one that is fundamentally intelligible to visual organisms like ourselves.

There is an ongoing philosophical discussion over whether representational content, subjective experience, energetic stimulus, selectively shaped sense organs, or some combination of these features should be the criteria used to construct a typology of biological senses. We will not delve into this debate here. Instead, we can simply make the pragmatic observation that how one thinks sensory modalities ought to be individuated depends on what explanatory role the concept is playing in the particular streams of scientific thought in which it is deployed.

Psychology-oriented accounts of sensory modalities are typically built around mental categories like representation and experience, whereas biology-oriented approaches have tended to eschew psychological factors in favor of physical and biochemical criteria. A contemporary defender of the biological approach is the philosopher Brian Keeley, who argues that "to possess a genuine sensory modality is to possess an appropriately wired up sense organ that is historically dedicated to facilitating behaviour with respect to an identifiable physical class of energy."[43] On this view, two token sensory modalities cannot be of the same type—or even in the same sensory space vicinity—if they process information that is produced by different classes of physical energy. Echolocation would thus be considered closer to hearing, and electrolocation closer to magnetoreception, than either are to vision.

There is a serious problem with this view, however, even if we presuppose the biological perspective. Selection molds traits for particular functions, and as we saw in part I, functional traits are multiply realizable. Wings, eyes, and filter-feeding devices can be, and have been, produced out of entirely different structures and molecular substrates. The same is true for sensory modalities, which are best delineated in virtue of their *selected function*, not the structures, substrates, or energies that realize them. Moreover, using energetic bases to delineate senses may be useful in the context of some scientific questions, but less so for others. As previously defined, ISMs are modes of imaging the surrounding world that overlap significantly in representational and phenomenal content. This psychological overlap is crucial, moreover, for explaining the evolution of complex brains and sophisticated behavior (see chapters 9 and 10). It is not vision qua vision, but *vision qua ISM*, that explains the coevolutionary feedback process that results in the neural, cognitive, motor, and behavioral complexification associated with the evolution of active intelligent animals. Understanding this complexification process requires delineating sensory modalities in terms of psychological and informational predicates that are multiply energetically realizable.

4.3 The Cosmic Umwelt

ISMs have been dominated by vision ever since their origin in the Cambrian. The same integration and unification problems that had to be solved (and solved repeatedly) for vision also had to be solved (and solved repeatedly) for alternative ISMs, such as echolocation and electrolocation. As we saw in chapter 7, these alternative ISMs support holistic object recognition and scene construction using entirely different waveform energetics as their informational basis. Contours, textures, motions, positions, affective valences, and even analogs of color are integrated into acoustic and electric object percepts, which retain their meaningful identities over space and time.

If Umweltian consciousness consists in, or arises from, the integrative informational structures that seamlessly stitch together the phenomenal scene, then the fact that this unification has been achieved convergently in alternative modes of image formation should make us even more confident in the cosmic nature of the Umwelt. No matter how bizarre and unimaginable the mental life of intelligent aliens might be, their first-personal portal on the world is likely to be fundamentally familiar. Consciousness binds minds and connects the cosmos.

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