Coda to Part II: Homage to *Homo Sapiens*

The evolutionary trajectory of this book might seem to be steamrolling straight into the inevitability of humanlike intelligence and technological prowess. This coda will throw a wrench into this optimistic juggernaut. The wrench in question is the radical contingency of human-grade cultural capacities, and it will help to resolve an old paradox that appears to have been given a new lease on life from the arguments canvassed in this book. If minds are robustly replicable outcomes of evolution, why is there no evidence for their cosmic existence?

1. Where Are They?

Over lunchtime conversation, the physicist Enrico Fermi asked why, if intelligent civilizations are so common in the universe, we have not a shred of evidence for their existence. "Fermi's paradox," as this question has become known, highlights a dissonance between the apparent observational entailments of a commonly held theory and our actual observations. The commonly held theory in question is the notion that intelligent life is widespread in the universe. The observational entailments of this theory are various empirically verifiable signatures of extraterrestrial intelligence discernable on Earth, in the solar system, and elsewhere in the galaxy (such as messages, artifacts, evidence of astroengineering, and visitations either by intelligent extraterrestrial organisms themselves or their autonomous machines). And these observational entailments are in tension with the "Great Silence" that descends upon us from the heavens.

In a recent book, Milan Ćirković, a proponent of the search for extraterrestrial intelligence (SETI), shows how Fermi's paradox arises from Copernican-style inferences (see chapter 1) about the cosmic typicality of terrestrial astronomy, geology, and biology as well as human-specific intelligences, technological capacities, and motivations.[1] Modern cosmology and astronomy have only strengthened the paradox, which Ćirković characterizes as one of the most profound and enduring problems of modern science. The present discussion lends considerable biological pressure to Fermi's paradox. Although part I argued that specific animal body plans may be radically contingent, part II showed that the evolution of mind transcends body plan constraints and is likely to be a robustly replicable feature of living worlds.

One obvious way of resolving the paradox is to reject the Copernican notion that human (or "peer-plus") grades of intelligence are cosmically typical. One can do this by targeting any of a number of jointly necessary conditions for the evolution of intelligent extraterrestrial life, such as those suggested by Peter Ward and Douglas Brownlee in their famous "Rare Earth" argument.[2] As the search for intelligent extraterrestrials continues, one great challenge before us is to identify biological focal points of contingency that could potentially dissolve the paradox. We have encountered several singular turning points in the history of life on Earth that present as good candidates, such as the evolution of eukaryote-grade cellular complexity and animal-grade morphological complexity—outcomes that are subject to observer selection effects and thus could account for the failure of Copernican principles.

In the homestretch of this book, we will highlight one important and underanalyzed condition for life to "progress" to a star-faring, or at least interstellar-communicating, civilization: the evolution human-grade technological capacities. Although this "step" was included as one of the fractions in the Drake equation (see chapter 1),[3] the formidable suite of contingencies that factor into the evolution of cumulative technological culture have been largely overlooked, and as a result the fraction of evolutionary histories that are expected to lead to robust technological civilizations has been overestimated.

The fact that cumulative technological culture—the stepwise improvement of technologies and the reliable transmission of these incremental improvements down the generations—was not achieved on Earth until so late in the evolutionary game bodes poorly for its cosmic replicability. In what follows, we will consider some explanations of this great delay and whether they can be marshaled into a tentative case for the radical contingency of robustly technological species. Navigating the fascinating landscape of human technological evolution would necessitate a book in its own right. What follows is just the dip of a theoretical toe into a vast and largely uncharted sea of empirically constrained speculation.

2. The Replicability of Higher Cognition

There is an enormous gap between the evolution of basic Umweltian minds, on the one hand, and the emergence of sophisticated technological cultures, on the other. Within this gap lie various "higher-cognitive" abilities on which the evolution of technological cultures is scaffolded. Precisely which higher cognitive abilities are implicated in the scaffolding of cumulative technology is unclear. However, causal reasoning, planning, imagination, means-ends rationality, metacognition, imitation, symbolism, self-awareness, and cognitive and cultural factors that underpin cooperation, communication, and social learning are all important parts of the story.

At the time of Stephen Jay Gould's writings on contingency, higher-cognitive properties were thought limited to human beings or at least to "higher" mammals like primates and cetaceans. Gould could be forgiven, therefore, for concluding that the evolution of humanlike cognitive properties on Earth were limited to mammals and thus hinged on the radically contingent dynamics of the dinosaur-mammal succession (discussed in chapter 2). Had a comet or asteroid never struck the Yucatán around 65 million years ago, or had it struck at a healthier time for dinosaurian ecosystems, the dinosaurs may have continued to dominate the cooler, dryer world of the Paleogene, precluding the diversification of mammals into their familiar modern orders (but see the discussion in chapter 2). Noting the lack of any detectable trend toward increasing brain complexity in dinosaurs, Gould surmised that the evolution of cognitive complexity may "lie outside the capabilities of reptilian design," and that therefore "we must assume that consciousness would not have evolved on our planet if a cosmic catastrophe had not claimed the dinosaurs as victims."[4]

The soundness of this claim depends, of course, on the sorts of cognitive complexity and consciousness that Gould is contemplating. As we have seen in part II, there is evidence for surprisingly sophisticated cognitive abilities and perhaps even consciousness in at least two phyla of invertebrates. Furthermore, it is evident that humanlike cognitive capacities are not, as Gould conjectured, beyond the capabilities of "reptilian" design. In fact, there are intelligent theropod dinosaurs living among us today: you might catch a glimpse of one silhouetted by the setting sun, or perhaps one is peering curiously over your shoulder as you read this. The dinosaurs of which we speak are, of course, birds. There is now a great deal of experimental evidence for complex cognition in birds, including causal reasoning, episodic-like memory, prospection, imagination, abstract concepts, language comprehension (both semantic and syntactic), numerosity, proto-moral behaviors, the multistage manufacture of tools, self-awareness, and metacognitive abilities such as the capacity to reflect on one's mental states.[5]

There is good reason to think that the impressive range of cognitive abilities exhibited by some living birds was also present, to some degree, in some of their extinct nonavian dinosaur relatives, especially the coelurosaurian theropods (which include raptors, tyrannosaurids, and compsognathids). Birds are more closely related to the feathered *Tyrannosaurus rex* than *T. rex* is to other nontheropodian dinosaurs (such as ceratopsians or apatosaurs) or even to other large theropods like *Allosaurus*. *T. rex* appears to have had a higher encephalization quotient (a measure of relative brain size) than living carnivores like dogs and cats.[6] This is perhaps not surprising, given that extinct theropods may have cooperated to solve more strategically complex foraging problems than those confronting modern birds—closer, perhaps, to lions and wolves hunting formidable prey in the grasslands and woodlands of our modern world. Maniraptorans, such as *Deinonychus* and other "raptors," had large, highly developed brains that were well matched for these tasks; indeed, the hypertrophy of the avian forebrain—which is analogous to the mammalian neocortex—began its evolutionary expansion deep in theropod evolution.[7]

All this suggests that the cognitive sophistication of birds was inherited to some extent from their extinct dinosaurian ancestors. Dinosaurs and mammals share a common ancestor that dates back to the Carboniferous, well before the great Permian catastrophe that would pave the way for the unlikely rise of the dinosaurs (see chapter 2). The convergent evolution of higher forms of cognition and consciousness in birds and mammals is thus indicative of a much deeper replicability of humanlike intelligence than Gould had entertained. Nevertheless, even cognitive convergence between dinosaurs and mammals is too phylogenetically "shallow" to support anything approaching cosmic levels of projectibility.

The fact that higher-cognitive convergence is confined to the vertebrate body plan could indicate that there are developmental limiting conditions on the evolution of very complex cognitive mechanisms that make these properties exceedingly rare among life worlds. Cognitive convergences between distant mammalian lineages, such as between whales and primates,[8] though striking, are even more restricted in their projectibility. In short, we cannot be confidant that iterations of higher cognition are free of developmental confounders if we only see patterns of cognitive convergence within a single body plan that is not itself subject to iteration.

3. Tool Use and Intelligence

Technology is closely (though not exclusively) associated with tool use, and tool use is a multiply-realizable behavior with a broad neural realization base. Defined in behavioral terms, tool use is a pervasively convergent phenomenon. However, only a small proportion of tool use among nonhuman animals is plausibly generated by higher-level cognition, such as planning, causal reasoning, insight, and working memory. Yet just as tool use per se does not necessarily indicate the presence of intelligence (in ants, for instance, it is likely "hard-wired"), the lack of tool use does not necessarily indicate the absence of intelligence. The dearth of tool use in intelligent clades could indicate that there are limiting conditions above and beyond higher cognition that restrict the evolution of technological cultures.

Consider, for instance, the general (though not categorical) lack of tool use in dolphins. Dolphins possess what is arguably the most complex mind in the extant animal world apart from that of humans, and this is reflected in the remarkable sophistication of dolphin brains, cognition, communication, culture, and society. Why is it, then, that humans—and not dolphins—are a space-faring species, even though toothed whales are a much older evolutionary lineage? Why do dolphins not dominate the oceans in the same way that humans dominate the terrestrial zone? Why is tool use in dolphins so rare, rather than a central axis of dolphin life?

Answers to these questions will be multifaceted, but ecological and developmental constraints on the evolution of tool use will be a critical part of the story. One major ecological constraint arises from the fact that the physics of tool use in water differ from that in air. Striking tools are less effective in water due to the energy dissipation that results from the higher density of water, which attenuates striking speeds. Buoyancy is another factor that constrains the striking efficacy and transportability of tools in water. And, of course, the manufacture of fire—a critical tool for external digestion, temperature regulation, and predator avoidance in humans—is forever inaccessible in the water medium. There are also numerous anatomical features that constrain the evolution of tool use in dolphins. Like fish, dolphins lack grasping appendages, and their rigid flippers and flukes have indispensable locomotory functions that preclude their modification into "hands" that are suited for tool manufacture and transport. Such transformations lie beyond the possibility space of dolphin body plan evolution.

In contrast, hominin bipedalism evolved in australopithecines for improved locomotory efficiency, freeing up the hands for subsequent technology-related modifications in *Homo*. There is now evidence that australopithecines—bipedal apes whose brain sizes were generally closer to those of chimpanzees than to those of early humans—were using tools manufactured through percussion more than 3 million years ago, well before the emergence of the first *Homo* species. What allowed these technological traditions to emerge in early hominins despite their chimp-sized brains?[9] Why did the distinctively human technology of *Homo erectus* exhibit bewilderingly little change on a global scale for over 1.5 million years?[10] If *erectus* populations were intelligent, intentional, foresighted, imaginative, symbolic, and proto or fully linguistic human beings who lived in highly cooperative societies with culturally scaffolded learning environments—as everything about their lifeways seems to suggest[11]—then why do we see a stunning lack of technological innovation for nearly the entire history of human evolution? Finally, what caused the great technology explosion that shattered this "Great Stagnance" just within the last 50,000 years? Many answers have been given to these questions, and all of them, or none of them, may be right. Our aim in the remaining pages is not to solve these enduring puzzles but merely to appreciate how ripe the landscape is for radical contingency.

4. Technology Made Human

The title of this section is intended as a double entendre. Not only does technology take on a uniquely cumulative character in modern humans, but in addition technological industry was a crucial driver of early human evolution. The transformation of *Homo* into an apex African predator[12] capable of migrating long distances and colonizing diverse environments represents a marked shift from the relatively simple "chimp-like" behavioral ecology of the australopithecines toward the highly cooperative lifeways of erectus-grade hominins. This shift could not have occurred without a technological industry that included tools for hunting, butchering, defense, and gathering; fire for cooking meats and hard-to-digest vegetables as well as for thermoregulation and keeping nocturnal predators at bay; primitive clothing which served as portable insulation; and basic sheltering techniques. Sustaining these industries, in turn, would have required the first "social technologies," including moral systems and culturally constructed learning environments.

Although the earliest direct evidence for the use of fire dates from 500,000 to 1.5 million years ago,[13] evolutionary anthropologist Richard Wrangham makes a persuasive case that the presence of cooking can be inferred from major changes in hominin skeletal anatomy and lifeways that indicate fire was in play at the evolutionary base of *erectus* around 1.7 million years ago.[14] These modifications include substantial reductions of teeth, jaws, and gut, an increase in hominin body size to modern human proportions, a switch to full-time life on the ground due to anatomical modifications for long-distance persistence hunting, and immigration into colder climes in Eurasia during glacial and interglacial periods despite having a body built for the tropics. If Wrangham's inference to the best explanation is right, then the reliable transmission of cooking, along with simple percussion-manufactured technologies (and probably gathering implements as well, which are unlikely to be preserved), were a crucial factor in the evolution of *erectus* from more primitive habilines. Technology quite literally made us human.

The deep conservation of *erectus* technology is bizarre from the standpoint of everything we know about these early humans. It may not only point to the very different character of human mind and culture in the Pleistocene, but also hint at the contingencies that may underlie the evolution of cumulative technological species. Within the last 100,000 years, stone tools and fire ignition technologies became more sophisticated, and projectile weapons, spearheads, and pulverizing tools were introduced. The "big bang" of cultural innovation occurred only within the last 40,000 years or so, with complex clothing, buttons, beads, jewelry, adornments, paintings, sculpture, religion, and music appearing on the scene, taking on the cultural morphology of human life as we know it.

Technological complexity was amplified again with the population boom and specialization of labor that followed in the wake of the Agricultural Revolution, and yet again with the mechanistic and methodological innovations of the Industrial and Scientific revolutions. Perhaps the next technological saltation will be driven by a revolution in artificial superintelligence.[15] Today, technology progresses at such a breakneck pace that older generations are compelled to acquire technological innovations from their descendants, reversing the intergenerational flow of cultural information that has characterized human societies for over a million years. In a break from nearly all of human history, technologies that are ubiquitous today bear essentially no resemblance to technologies that are hundreds or thousands, let alone millions, of years old. What forces were responsible for this sudden technological expansion?

5. Let the Parlor Games Begin

Cumulative culture was first posed as a central evolutionary explanandum by primatologist Michael Tomasello and colleagues in the early 1990s.[16] Their basic insight was that the cultural scaffolding of knowledge, skills, and material innovations enables descendants to build on the accumulated corpus of technical information that has been compiled and retained by ancestral generations. This scaffolding obviates the need for individuals to reinvent innovations in each generation through insight, trial-and-error learning, or luck, which in turn allows for the stepwise improvement of technologies that we take for granted today. In effect, cumulative technological culture extends the circle of co-operators beyond the grave to include distant generations of teachers and innovators. In contrast, the spread of technical innovations in nonhuman animals, such as chimpanzees, relies primarily on individual inventiveness, socially mediated trial-and-error learning, and imitation—vectors of technical innovation that are insufficient to produce what Tomasello and colleagues call the "cultural ratchet," which they argue is the key to human evolutionary success.[17]

Some of the factors that permit the spread of innovations in chimps are likely to figure in human cultural transmission as well. A central task of human evolutionary science, however, is to home in on the difference-making factors that contribute to the ratchet-like character of human culture. This project is ongoing and implicates a multitude of interwoven biocultural capacities, including symbolic language, communicative gestures, perspective-taking, mind reading, physical cognition, planning, insight, mental time travel, functional representations, cooperative motives, pedagogy, normative concepts and structures, and other traits that are not present, or not present to significant degrees, in nonhuman animals.

Part of the difficulty in making headway on this problem is that many of the implicated adaptations seem to have arisen well before the technological accelerations that we are trying to explain, and thus do not seem to be difference-making causes of cumulative culture, even if they are necessary ones. This temporal gap problem arises for spoken language,[18] symbolism, theory of mind, perspective-taking, joint intentionality,[19] mental simulation,[20] sophisticated causal reasoning,[21] functionalist orientations toward objects and artifacts,[22] normativity,[23] and other cognitive features that are apparently unique to humans. Other relevant traits, such as manual dexterity—including the precision-pinch and squeeze grip—precede the emergence of stone-tool manufacture altogether.[24]

The time lag problem is illustrated by two key traits that underpin the evolution of industry: language and morality. Language almost certainly coevolved with technology, enhancing the efficiency of interpersonal communication and with it the cultural ability to pass down innovations with ever greater precision and reliability. However, there is a large temporal gap between evolution of language and the very late emergence of cumulative technology in humans. As noted earlier, there is strong circumstantial evidence that *erectus* had language. There is even stronger evidence, based on comparative genomics,[25] that language was present in the last common ancestor of sapiens and Neanderthals, *Homo heidelbergensis*, who was a later variant of *erectus* that lived some 500,000 years ago. Both *erectus* and *heidelbergensis* were probably linguistic and to some extent symbolic, yet neither evolved cumulative culture. The earliest known cave paintings were painted not by Sapiens but by Neanderthals, who *ex hypothesi* lacked cumulative culture.[26] It seems more likely, then, that rather than language and symbolism ushering in behavioral modernity, cumulativity allowed language and symbolism to thrive in a way that they could not do before.

Normativity provides another crucial ingredient in the emergence of cumulative technology. It is hard to imagine anything approaching the levels of cooperation achieved by early humans, let alone the ultra-cooperation of modern human societies, without social norms to structure, coordinate, and incentivize cooperative behavior. The prevailing view is that morality was selected in early human groups (likely in the late Pleistocene) for managing intragroup conflicts that would otherwise impede collective action. Morality did this by reducing free-riding through the administration of punishment, by inculcating altruistic attitudes that enabled individuals to resist the temptation to act selfishly, and by enforcing an antihierarchical ethos that prevented dominant individuals from monopolizing the fruits of cooperation.[27]

The rewards of this new-found cooperation were substantial and far exceeded what could have been achieved alone or in groups with poor coordination. Moral systems were likely present in *heidelbergensis* at least 400,000 years ago, and probably earlier as indicated by levels of cooperation in *erectus*, which appears to have included highly deliberative and collaborative seafaring voyages that established populations on isolated Asian islands like Java and Flores. Both language and morality were crucial for constructing the learning environments in which technological traditions could be reliably sustained and improved upon. Yet both language and morality predated cumulative culture by hundreds of thousands if not more than a million years.

In his book *The Evolved Apprentice*, Kim Sterelny distinguishes between two types of cultural cumulativity that characterize behavioral modernity.[28] The first is the sheer volume and diversity of material artifacts that begin to be forged from a wider array of material substrates; the second is the stepwise improvement of technologies through incremental modifications that are retained and transmitted down the generations. Sterelny attributes the first feature to the increasing bandwidth of cultural learning, or the magnitude of information that culture is capable of transmitting; he attributes the second feature to the increasing fidelity of cultural transmission. The high-volume, high-fidelity features of human culture were made possible, Sterelny argues, by the creation of apprenticeship institutions. These include the explicit teaching of crafts and design as well as the organization of a learning space in which apprentices could learn by exploring and experimenting with the materials and by-products of the design process. Over time, the coevolution of numerous cognitive and social factors, such as social attuning mechanisms (e.g., joint intentionality), copying biases (e.g., a tendency toward conformity), larger populations (in which innovations are more likely to arise and be preserved), and more elaborate normative categories (e.g., the concepts of "teacher" and "student"), would enhance the cumulative capacities of culture.

If cumulative technology requires cooperatively scaffolded learning environments, and if these cooperative structures are underpinned not only by language but also by normative judgments and concepts, then the evolution of cumulative technology requires the evolution of normativity. Like language, normativity appears to have very low evolvability due to both its cognitive demandingness and the limited ecological conditions under which altruism can evolve. Modeling and ethnographic work have shown that the norms underpinning cooperation will not be sufficiently adhered to and free-riding strategies will tend to invade unless moral norms are coercively enforced through institutions of moralizing punishment.[29] If punishment is expensive to carry out, then the evolution of third-party punishment appears to pose a higher-order altruism problem that only group-level selection can solve. If this is right, then we are faced, in effect, with an evolutionary catch-22: competition among cohesive cultural groups is a necessary condition for the evolution of punishment and hence for morality to get off the ground, but institutionalized punishment is a necessary condition for the coherence and stability of cultural groups. Perhaps these two aspects could evolve in tandem, but we can begin to see why it is so difficult to evolve the normative structures that underpin cumulative technology.

6. A Silence Less Eerie

In short, cumulative culture hinges on the confluence of a large number of anatomical, cognitive, and social adaptations, each of which is exceedingly rare in the animal world if not exclusively possessed by humans. It is plausible to think that all or many of these components must be in place for cumulative culture to take off, even if we are uncertain as to why culture became cumulative when it did. Most of the adaptations implicated in cumulative culture have plausible selective functions in their own right; only later were they coopted in the service of cultural cumulativity. If this complex exaptation picture is correct, then it could explain the great time lag between the origins of key components of culture and the emergence of cultural cumulativity.

How might the evolution of some components of cumulative culture have affected the evolution of others? This is an important question for our present purposes because coevolutionary feedback loops can make certain outcomes more evolutionarily robust. We have seen that image-forming eyes, brains, and able bodies coevolved to produce the first mindful animals on Earth. Do similar coevolutionary feedback processes make the evolution of cumulative culture more likely? There have almost certainly been feedback effects in human biocultural evolution, most obviously between cognition on the one hand and the complexity of human cooperative societies and technological industries on the other. The evolution of language, mind reading, causal reasoning, and pedagogy-related adaptations would have facilitated the cultural construction of learning environments in which more sophisticated technical skills and norms could be acquired, which in turn would have become potent new sources of selection pressures for enhanced cognitive functions, and so on.

Feedback loops of this sort presumably drove the rapid expansion of the human brain and the swift complexification of human societies and industries that we see over the middle to late Pleistocene. It is certainly conceivable that other post-*erectus* human clades, such as the Neanderthals or Denisovans, might have independently evolved cumulative culture had they not been nudged into extinction by their more robustly cultural cousins, the Sapiens. However, the Neanderthals and Denisovans shared (via common ancestry) a large number of the singular adaptations that underlie cumulative culture in Sapiens, and so any hypothetical iterations of cumulative culture in these hominin clades would amount to Gouldian repetitions rather than true convergence—and repetitions with a very shallow replicability depth at that.

Even if feedback dynamics played a role in the evolution of cultural cumulativity, they do not rescue technological species from the jaws of radical contingency. There is no reason to think that there is any single, let alone robustly replicable, innovation that could account for the emergence of a complexly configured exaptation like cumulative culture. Rather than a Sherlock Holmes murder mystery that can be pinned unequivocally on a single culprit, the evolution of cumulative culture is more like the film *Murder on the Orient Express* (1974), in which each of twelve suspects turns out to have stabbed the victim in a vastly unlikely conspiracy. If there is a "Great Filter"[30] in the emergence of intelligent civilizations that dissolves the Fermi paradox, it may very well be at this juncture, in the evolution of cumulative technological species.

7. Summary of Part II

The upshot of part II is that mind in the rich Umweltian sense is likely to emerge across deep replays of the tape of animal life on Earth. The bolder proposition that the Umwelt is a ubiquitous feature of the living cosmos remains highly plausible but cannot be established beyond a reasonable doubt at this time. This is because there are lingering uncertainties about the contingent or replicable nature of some key evolutionary transitions and innovations in the history of life about which there is still great uncertainty. Nevertheless, a strong case can be made, based on patterns of convergence, for the striking notion that minds of a particular sort are written into the living fabric of the universe. Even if minds turn out to be relatively uncommon, wherever they *do* arise, they are likely to assume an Umweltian character—not because we cannot imagine minds any other way, but because evolution does not (or cannot) build minds any other way. Wherever minds are found, they are likely to have deep similarities to our own. This conclusion lends considerable pressure to Fermi's paradox. However, if the unique suite of cognitive capacities that underpins cumulative culture in behaviorally modern humans is radically contingent, this would explain the very late emergence of robust technology in the history of life on Earth and the puzzling lack of evidence for the ubiquity of other older, wiser we's out there in the universe.

Contingency and Convergence

Toward a Cosmic Biology of Body and Mind

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