

The cognitive niche: Coevolution of intelligence, sociality, and language

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Although Darwin insisted that human intelligence could be fully explained by the theory of evolution, the codiscoverer of natural selection, Alfred Russel Wallace, claimed that abstract intelligence was of no use to ancestral humans and could only be explained by intelligent design. Wallace's apparent paradox can be dissolved with two hypotheses about human cognition. One is that intelligence is an adaptation to a knowledge-using, socially interdependent lifestyle, the "cognitive niche." This embraces the ability to overcome the evolutionary fixed defenses of plants and animals by applications of reasoning, including weapons, traps, coordinated driving of game, and detoxification of plants. Such reasoning exploits intuitive theories about different aspects of the world, such as objects, forces, paths, places, states, substances, and other people's beliefs and desires. The theory explains many zoologically unusual traits in *Homo sapiens*, including our complex toolkit, wide range of habitats and diets, extended childhoods and long lives, hypersociality, complex mating, division into cultures, and language (which multiplies the benefit of knowledge because know-how is useful not only for its practical benefits but as a trade good with others, enhancing the evolution of cooperation). The second hypothesis is that humans possess an ability of *metaphorical abstraction*, which allows them to coopt faculties that originally evolved for physical problem-solving and social coordination, apply them to abstract subject matter, and combine them productively. These abilities can help explain the emergence of abstract cognition without supernatural or exotic evolutionary forces and are in principle testable by analyses of statistical signs of selection in the human genome.

cognition | human evolution | metaphor

The bicentennial of Darwin's birth and sesquicentennial of the publication of the *Origin of Species* have focused the world's attention on the breathtaking scope of the theory of natural selection, not least its application to the human mind. "Psychology will be based on a new foundation," Darwin famously wrote at the end of the *Origin*, "that of the necessary acquirement of each mental power and capacity by gradation. Light will be thrown on the origin of man and his history."

Far less attention has been given to the codiscoverer of natural selection, Alfred Russel Wallace, despite his prodigious scientific genius, and it is unlikely that the bicentennial of his birth in 1823 will generate the same hoopla. One reason was that Wallace turned out to be less prescient about the power of natural selection as an explanation of adaptive complexity in the living world. In particular, Wallace notoriously claimed that the theory of evolution by natural selection was inadequate to explain human intelligence:

Our law, our government, and our science continually require us to reason through a variety of complicated phenomena to the expected result. Even our games, such as chess, compel us to exercise all these faculties in a remarkable degree. . . . A brain slightly larger than that of the gorilla would . . . fully have sufficed for the limited mental development of the savage; and we must therefore admit that the large brain he actually possesses could never have been solely developed by any of those laws of evolution, whose essence is, that they lead to a degree of organization exactly proportionate to the wants of each species, never beyond those wants. . . .

Natural selection could only have endowed savage man with a brain a few degrees superior to that of an ape, whereas he actually pos-

sesses one very little inferior to that of a philosopher. (1, pp. 340, 343.)

The upshot, claimed Wallace, was that "a superior intelligence has guided the development of man in a definite direction, and for a special purpose (1, p 359)."

Few scientists today accept Wallace's creationism, teleology, or spiritualism. Nonetheless it is appropriate to engage the profound puzzle he raised; namely, why do humans have the ability to pursue abstract intellectual feats such as science, mathematics, philosophy, and law, given that opportunities to exercise these talents did not exist in the foraging lifestyle in which humans evolved and would not have parlayed themselves into advantages in survival and reproduction even if they did?

I suggest that the puzzle can be resolved with two hypotheses. The first is that humans evolved to fill the "cognitive niche," a mode of survival characterized by manipulating the environment through causal reasoning and social cooperation. The second is that the psychological faculties that evolved to prosper in the cognitive niche can be coopted to abstract domains by processes of metaphorical abstraction and productive combination, both vividly manifested in human language.

The Cognitive Niche

The term cognitive niche was proposed by Tooby and DeVore (2) to explain the constellation of zoologically unusual features of modern *Homo sapiens* without resorting to exotic evolutionary mechanisms.

Their account begins with the biological commonplace that organisms evolve at one another's expense. With the exception of fruit, virtually every food source of one animal is a body part of some other organism, which would just as soon keep that body part for itself. As a result, organisms evolve defenses against being eaten. Animals evolve speed, stealth, armor, and defensive maneuvers. Plants cannot defend themselves with their behavior, so they resort to chemical warfare, and have evolved a pharmacopeia of poisons, irritants, and bitter-tasting substances to deter herbivores with designs on their flesh. In response, eaters evolve measures to penetrate these defenses, such as offensive weapons, even greater speed or stealth, and organs such as the liver that detoxify plant poisons. This in turn selects for better defenses, selecting for better offenses, and so on, in a coevolutionary arms race, escalating over many generations of natural selection.

Tooby and DeVore (2) suggest that humans exploit a cognitive niche in the world's ecosystems. In biology, a "niche" is sometimes defined as "the role an organism occupies in an ecosystem." The cognitive niche is a loose extension of this concept, based on the idea that in any ecosystem, the possibility exists for an organism to overtake other organisms' fixed defenses by cause-and-effect reasoning and cooperative action—to deploy information and

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inference, rather than particular features of physics and chemistry, to extract resources from other organisms in opposition to their adaptations to protect those resources. These inferences are played out internally in mental models of the world, governed by intuitive conceptions of physics, biology, and psychology, including the psychology of animals. It allows humans to invent tools, traps, and weapons, to extract poisons and drugs from other animals and plants, and to engage in coordinated action, for example, fanning out over a landscape to drive and concentrate game, in effect functioning like a huge superorganism. These cognitive stratagems are devised on the fly in endless combination suitable to the local ecology. They arise by mental design and are deployed, tested, and fine-tuned by feedback in the lifetimes of individuals, rather than arising by random mutation and being tuned over generations by the slow feedback of differential survival and reproduction. Because humans develop offenses in real time that other organisms can defend themselves against only in evolutionary time, humans have a tremendous advantage in evolutionary arms races. Even before the current anthropogenic mass extinction, prehistoric humans are believed to have caused significant extinctions of large fauna whenever they first entered an ecosystem.

The theory of the cognitive niche helps explain many zoologically unusual features of *H. sapiens*: traits that are universal across human cultures (3) but are either unique or hyperdeveloped (especially in combination) with respect to the rest of the animal kingdom. Three in particular make our species stand out.

Technological Know-How. Humans use and depend upon many kinds of tools, which involve multiple parts and complicated methods of fabrication. The tools are deployed in extended sequences of behavior and are acquired both by individual discovery and learning from others. They are deployed to capture and kill animals, to process foods (including cooking, fermenting, soaking, peeling, and crushing them to remove toxins and increase the availability of nutrients), and to generate and administer medicinal drugs (4, 5). This reasoning is supported by “intuitive theories”—folk understandings of physics (in particular, objects, substances, and the forces that impinge on them), geometry (places, paths, and directions), biology (essences that give organisms their form and propel their growth, motion, and physiological processes), and psychology (internal, immaterial beliefs and desires) (6–10).

Cooperation Among Nonkin. Humans cooperate with other humans: they trade goods, favors, know-how, and loyalty, and act collectively in child-rearing, gathering, hunting, and defense. This cooperation extends to other humans who are not related to them, in shifting partnerships, coalitions, and trading relationships, and thus must be explained not by kin selection but by mutualism or reciprocity (11).

The evolution of cooperation by reciprocal altruism requires a number of cognitive adaptations, which in fact appear to be well-developed in humans (11). They include the recognition of individuals (12); episodic memory for their actions (13); an ability to classify those actions in terms of whether they violate a reciprocity contract (14, 15); a suite of moral emotions such as sympathy, gratitude, anger, guilt, and trust, which impel an individual to initiate cooperation, reward reciprocators, and punish cheaters (11, 16); and the drives to ascertain the competence, integrity, and generosity of others (through gossip and other forms of due diligence) and to burnish one’s own reputation for these traits (17, 18).

Because humans cooperate by at least three different kinds of relationship, governed by incompatible rules for the distribution of resources—reciprocal altruism, mutualistic sharing, deferring to dominant individuals—dyads can dynamically switch among kinds of relationship according to their history, kinship, social support, the resource at stake, and the context (19). The demands of this negotiation account for many of the complex aspects of human social life such as politeness, hypocrisy, ritual, and taboo (20, 21).

Grammatical Language. Although many animals communicate, humans appear to be unique in using an open-ended combinatorial system, grammatical language. In grammatical language, signals (words) are arbitrarily paired with concepts, and can be rearranged in novel hierarchical configurations (phrases embedded within phrases) in such a way that the meaning of the sequence can be computed from the meanings of the individual symbols and the way that they are arranged (22–24). The semantic meanings of the symbols (nouns, verbs, prepositions, tense markers, and so on) are related to the basic cognitive categories that define intuitive theories: objects, substances, motion, causation, agency, space, time (9, 25). The syntactic arrangements serve to express relationships among these concepts such as who did what to whom, what is where, and what is true of what (9). Although every language must be learned, humans have an ability to coin, pool, and learn new words and rules and thus are not dependent on some other species as teachers (as is the case with apes), or even on a longstanding linguistic community, to develop and use language (26).

Grammatical language has clear advantages in the transmission of information. Because it allows messages to be composed out of elements, rather than drawn from a finite repertoire, it confers the ability to express an unlimited number of novel messages (27, 28). Journalists say that when a dog bites a man, that is not news, but when a man bites a dog, that *is* news: the power of grammar is that it allows us to convey news, by arranging familiar words in novel combinations. Like other digital combinatorial systems in biology (RNA, DNA, proteins), language can generate vast numbers of structured combinations. The number of possible sentences (each corresponding to a distinct message) is proportional to the number of words that may appear in a position in a sentence raised to the power of the length of the sentence. With an approximate geometric mean of ten choices available at every position in a sentence, one can estimate that a typical English speaker can easily produce or comprehend at least 10^{20} distinct sentences (29). This in turn makes it possible for language users to share an unlimited number of messages concerning specific events (who did what to whom, when, where, and why), generalized expertise (to accomplish this, do that), and flexible social contracts (if you do this, I’ll do that).

Anyone who is skeptical that sophisticated reasoning, collaboration, and communication can bring survival advantages in a prehistoric lifestyle need only read ethnographic accounts of hunting or gathering in contemporary foraging peoples. One of many examples of hunter-gatherer ingenuity can be found in this description from the anthropologist Napoleon Chagnon of how the Yanomamö hunt armadillo:

Armadillos live several feet underground in burrows that can run for many yards and have several entries. When the Yanomamö find an active burrow, as determined by the presence around the entry of a cloud of insects found nowhere else, they set about smoking out the armadillo. The best fuel for this purpose is a crusty material from old termite nests, which burns slowly and produces an intense heat and much heavy smoke. A pile of this material is ignited at the entry of the burrow, and the smoke is fanned inside. The other entries are soon detected by the smoke rising from them, and they are sealed with dirt. The men then spread out on hands and knees, holding their ears to the ground to listen for armadillo movements in the burrow. When they hear something, they dig there until they hit the burrow and, with luck, the animal. They might have to try several times, and it is hard work—they have to dig down two feet or more. On one occasion, after the hunters had dug several holes, all unsuccessful...one of them ripped down a large vine, tied a knot in the end of it, and put the knotted end into the entrance. Twirling the vine between his hands, he slowly pushed it into the hole as far as it would go. As his companions put their ears to the ground, he twirled the vine, causing the knot to make a noise, and the spot was marked. He broke off the vine at the burrow entrance, pulled out the piece in the hole, and laid it on the ground along the axis of the burrow. The others dug down at the place where they had heard the knot and found the armadillo on their first attempt, asphyxiated from the smoke (30, pp 78–79.).

This jackpot was a reward for extraordinary feats of folk reasoning in taxonomy, physiology, physics, and geometry, some passed down from earlier generations, some improvised on the spot. And it depended on cooperative behavior among many individuals, coordinated by language.

Other Extreme Human Traits. Other zoologically unusual features of *H. sapiens* may be explained by the theory of the cognitive niche. The vast range of habitats and foods exploited by our species may in part have been facilitated by natural selection of the genes in local populations to ambient conditions such as solar radiation, diet, and disease (31–34). But these local adaptations pale in comparison with those made possible by human technology. The Inuit's colonization of high latitudes may have been facilitated by adaptive changes in body shape and skin pigmentation, but it depended much more on parkas, kayaks, mukluks, igloos, and harpoons. This underscores that the cognitive niche differs from many examples of niches discussed in biology in being defined not as a particular envelope of environmental variables (temperature, altitude, habitat type, and so on), nor as a particular combination of other organisms, but rather the opportunity that any environment provides for exploitation via internal modeling of its causal contingencies.

Our extended childhoods may serve as an apprenticeship in a species that lives by its wits, and our long lives may reflect a tilt in the tradeoff between reproduction and somatic maintenance toward the latter so as to maximize the returns on the investment during childhood. The dependence of children's readiness for adulthood on their mastery of local culture and know-how may also shift the balance in male parental investment decisions between caring for existing offspring and seeking new mating opportunities. This in turn may have led to biparental care, long-term pair bonding, complex sexuality (such as female sexuality being unlinked from fertility, and sexual relationships subject to variation and negotiation), and multigeneration parental investment (35). Support for these hypotheses comes from the data of Kaplan (36), who has shown that among hunter-gatherers, prolonged childhood cannot pay off without long life spans. The men do not produce as many calories as they consume until age 18; their output then peaks at 32, plateaus through 45, then gently declines until 65. This shows that hunting is a knowledge-dependent skill, invested in during a long childhood and paid out over a long life.

Finally, the division of humankind into cultures differing in language, customs, mores, diets, and so on, is a consequence of humans' dependence on learned information (words, recipes, tool styles, survival techniques, cooperative agreements, and customs) and their peripatetic natures. As splinter groups lose touch with their progenitors over time, the know-how and customs that the two groups accumulate will diverge from one another (37).

Hominid Evolution and the Cognitive Niche. Given that the opportunity to exploit environments by technology and cooperation are independent of particular ecosystems, why was it Pliocene hominids that entered (or, more accurately, constructed) the cognitive niche and evolved sophisticated cognition, language, and sociality, rather than a population from some other taxon or epoch? This kind of historical question is difficult, perhaps impossible, to answer precisely because the unusualness of *H. sapiens* precludes statistical tests of correlations between the relevant traits and environments across species. But if we consider the cognitive niche as a suite of mutually reinforcing selection pressures, each of which exists individually in weaker form for other species, we can test whether variation in intelligence within a smaller range, together with a consideration of the traits that were likely possessed by extinct human ancestors, supports particular conjectures.

Obviously any orthogenetic theory (such as Wallace's) stipulating that the emergence of our species was the goal of the evolutionary process is inconsistent with the known mechanisms of

evolution. It is also apparent that intelligence, which depends on a large brain, is not a free good in evolution (38). Its costs include the metabolic demands of expensive neural tissue, compromises in the anatomy of the female pelvis necessary for bearing a large-headed offspring, and the risks of harm from birth, falls, and the mutation and parasite load carried by such a complex organ. The proper framing of the question must ask which circumstances made the benefits of intelligence outweigh the costs. The hypothesis is that the hominid ancestors, more so than any other species, had a collection of traits that had tilted the payoffs toward further investment in intelligence.

One enabling factor may have been the possession of prehensile hands (an adaptation to arboreality) in combination with bipedality (presumably an adaptation to locomotion). We know from the fossil record that both preceded the expansion of the brain and the development of tool use (39). Perhaps the availability of precision manipulators meant that any enhanced ability to imagine how one might alter the environment could be parlayed into the manufacture and carrying of tools.

A second contributor to the evolution of intelligence among hominid ancestors may have been an opportunistic diet that included meat and other hard-to-obtain sources of protein (5). Meat is not only a concentrated source of nutrients for a hungry brain but may have selected in turn for greater intelligence, because it requires more cleverness to outwit an animal than to outwit fruit or leaves.

A third may have been group living, again with the possibility of positive feedback: groups allow acquired skills to be shared but also select for the social intelligence needed to prosper from cooperation without being exploited.

Indirect support for the hypothesis that sociality and carnivory contributed to the evolution of human intelligence comes from comparative studies showing that greater intelligence across animal species is correlated with brain size, carnivory, group size, and extended childhoods and lifespans (40, 41). I am unaware of any review that has looked for a correlation between possession of prehensile appendages and intelligence, although it is tantalizing to learn that octopuses are highly intelligent (42).

Coevolution of Cognition, Language, and Sociality. Many biologists argue that a niche is something that is *constructed*, rather than simply entered, by an organism (43, 44). An organism's behavior alters its physical surroundings, which affects the selection pressures, in turn selecting for additional adaptations to exploit that altered environment, and so on. A classic example is the way beavers generated an aquatic niche and evolved additional adaptations to thrive in it. The particulars of a *cognitive* niche are similarly constructed, in the sense that initial increments in cooperation, communication, or know-how altered the social environment, and hence the selection pressures, for ancestral hominids. It is surely no coincidence that the psychological abilities underlying technological know-how, open-ended communication, and cooperation among nonkin are all hyperdeveloped in the same species; each enhances the value of the other two. (A similar feedback loop may connect intelligence with the life-history and behavioral-ecology variables mentioned in the preceding section.)

An obvious interdependency connects language and know-how. The end product of learning survival skills is information stored in one's brain. Language is a means of transmitting that information to another brain. The ability to share information via language leverages the value of acquiring new knowledge and skills. One does not have to recapitulate the trial-and-error, lucky accidents, or strokes of genius of other individuals but can build on their discoveries, avoiding the proverbial waste of reinventing the wheel.

Language not only lowers the cost of acquiring a complex skill but multiplies the benefit. The knowledge not only can be exploited to manipulate the environment, but it can be shared with kin and other cooperators. Indeed, among commodities, infor-

mation is unusually conducive to being shared because it is what economists call a “nonrival good”: it can be duplicated without loss. If I give you a fish (a rival good), I no longer have the fish; as the saying might have gone, you cannot eat your fish and have it. But if I teach you to fish, it does not mean that I am now amnesic for the skill of fishing; that valuable commodity now exists in twice as many copies. Language can multiply this proliferation: for the minor cost of a few seconds of breath, a speaker can confer on a listener the invaluable benefit of a new bit of know-how. Crucially, a commodity that confers a high benefit on others at a low cost to the self is a key ingredient in the evolution of cooperation by reciprocal altruism, because both parties can profit from their exchange over the long run (11). The ability to share know-how through language thus may have been a major accelerant in the evolution of cooperation because it gives humans both the incentive and the means to cooperate. People can trade not only goods but know-how and favors, and the negotiations are not limited to what can be exchanged there and then but to goods and favors transferred at widely separated times.

Language may foster cooperation, but it also depends on it, because there is no advantage in sharing information with adversaries (as we see in the expression “to be on speaking terms”). The inherent synergies among language, intelligence, sociality, enhanced paternal and grandmaternal investment, extended lives and childhoods, and diverse habitats and food sources suggest that these features cohere as a characterization of the cognitive niche, with enhancements in each serving as an additional selection pressure for the others. As far as timing is concerned, we would expect that the corresponding adaptations coevolved gradually, beginning with the first hominid species that possessed some minimal combination of preconditions (e.g., bipedality, group living, omnivory), increasing in complexity through the lineage of species that showed signs of tool use, cooperation, and anatomical adaptations to language, and exploding in behaviorally modern *H. sapiens*.

Evaluating the Theory of the Cognitive Niche

The theory of the cognitive niche, I believe, has several advantages as an explanation of the evolution of the human mind. It incorporates facts about the cognitive, affective, and linguistic mechanisms discovered by modern scientific psychology rather than appealing to vague, prescientific black boxes like “symbolic behavior” or “culture.” To be specific: the cognitive adaptations comprise the “intuitive theories” of physics, biology, and psychology; the adaptations for cooperation comprise the moral emotions and mechanisms for remembering individuals and their actions; the linguistic adaptations comprise the combinatorial apparatus for grammar and the syntactic and phonological units that it manipulates.

The selection pressures that the theory invokes are straightforward and do not depend on some highly specific behavior (e.g., using projectile weapons, keeping track of wandering children) or environment (e.g., a particular change in climate), none of which were likely to be in place over the millions of years in which modern humans evolved their large brains and complex tools. Instead it invokes the intrinsic advantages of know-how, cooperation, and communication that we recognize uncontroversially in the contemporary world. Science and technology, organizations (such as corporations, universities, armies, and governments), and communication media (such as the press, mail, telephones, television, radio, and the internet) are, respectively, just the exercise of cognition, sociality, and language writ large, and they singly and jointly enable the achievement of outcomes that would be impossible without them. The theory of the cognitive niche simply extrapolates these advantages backward in time and scale.

Moreover, the theory requires no radical revision to evolutionary theory: neither the teleology and creationism of Wallace, nor mechanisms that are exotic, extreme, or invoked ad hoc for our species. Although grammatical language is unique to humans, and our intelligence and sociality are hyperdeveloped, it is not

uncommon for natural selection to favor unique or extreme traits, such as the elephant’s trunk, the narwhal’s tusk, the whale’s baleen, the platypus’s duckbill, and the armadillo’s armor. Given the undeniable practical advantages of reasoning, cooperation, and communication, it seems superfluous, when explaining the evolution of human mental mechanisms, to assign a primary role to macromutations, exaptation, runaway sexual selection, group selection, memetics, complexity theory, cultural evolution (other than what we call “history”), or gene–culture coevolution (other than the commonplace that the products of an organism’s behavior are part of its selective environment).

The theory can be tested more rigorously, moreover, using the family of relatively new techniques that detect “footprints of selection” in the human genome (by, for example, comparing rates of nonsynonymous and synonymous base pair substitutions or the amounts of variation in a gene within and across species) (32, 45, 46). The theory predicts that there are many genes that were selected in the lineage leading to modern humans whose effects are concentrated in intelligence, language, or sociality. Working backward, it predicts that any genes discovered in modern humans to have disproportionate effects in intelligence, language, or sociality (that is, that do not merely affect overall growth or health) will be found to have been a target of selection. This would differentiate the theory from those that invoke a single macromutation, or genetic changes that affected only global properties of the brain like overall size, or those that attribute all of the complexity and differentiation of human social, cognitive, or linguistic behavior to cultural evolution. It is not necessary that any of these genes affect just a single trait, that they be the *only* gene affecting the trait (“the altruism gene,” “the grammar gene,” and so on) or that they appear de novo in human evolution (as opposed to being functional changes in a gene found in other mammals). The only requirement is that they contribute to the modern human version of these traits. In practice, the genes may be identified as the normal versions of genes that cause disorders of cognition (e.g., retardation, thought disorders, major learning disabilities), disorders of sociality (e.g., autism, social phobia, antisocial personality disorder), or disorders of language (e.g., language delay, language impairment, stuttering, and dyslexia insofar as it is a consequence of phonological impairment). Alternatively, they may be identified as a family of alleles whose variants cause quantitative variation in intelligence, personality, emotion, or language.

Several recent discoveries have supported these predictions. The gene for the transcription factor FOXP2 is monomorphic in normally developing humans, and when it is mutated it causes impairments in speech, grammar, and orofacial motor control (47, 48). The human version shows two differences from the version found in great apes, at least one of them functional, and the ape homolog shows only a single, nonfunctional difference from the one found in mice. The pattern of conservation and variation has been interpreted as evidence for a history of selection in the human lineage (49). In addition, several genes expressed in development of auditory system differ in humans and chimpanzees and show signs of selection in the human lineage. Because the general auditory demands on humans and chimps are similar, it is likely that they were selected for their utility in the comprehension of speech (50). And the human ASPM gene, which when mutated causes microcephaly and lowered intelligence, also shows signs of selection in the generations since our common ancestor with chimpanzees (51). It is likely that many more genes with cognitive, social, and linguistic effects will be identified in the coming years, and the theory of the cognitive niche predicts that most or all will turn out to be adaptively evolved.

Emergence of Science and Other Abstract Endeavors

Even if the evolution of powerful language and intelligence were explicable by the theory of the cognitive niche, one could ask, with Wallace, how cognitive mechanisms that were selected for physical and social reasoning could have enabled *H. sapiens* to

engage in the highly abstract reasoning required in modern science, philosophy, government, commerce, and law.

A key part of the answer is that, in fact, humans *do not* readily engage in these forms of reasoning (9, 10, 52). In most times, places, and stages of development, people's abilities in arithmetic consist of the exact quantities "one," "two," and "many," and an ability to estimate larger amounts approximately (53). Their intuitive physics corresponds to the medieval theory of impetus rather than to Newtonian mechanics (to say nothing of relativity or quantum theory) (54). Their intuitive biology consists of creationism, not evolution, of essentialism, not population genetics, and of vitalism, not mechanistic physiology (55). Their intuitive psychology is mind-body dualism, not neurobiological reductionism (56). Their political philosophy is based on kin, clan, tribe, and vendetta, not on the theory of the social contract (57). Their economics is based on tit-for-tat back-scratching and barter, not on money, interest, rent, and profit (58). And their morality is a mixture of intuitions of purity, authority, loyalty, conformity, and reciprocity, not the generalized notions of fairness and justice that we identify with moral reasoning (16).

Nonetheless, *some* humans were able to invent the different components of modern knowledge, and all are capable of learning them. So we still need an explanation of how our cognitive mechanisms are capable of embracing this abstract reasoning.

The key may lie in a psycholinguistic phenomenon that may be called *metaphorical abstraction* (9, 59–61). Linguists such as Ray Jackendoff, George Lakoff, and Len Talmy have long noticed that constructions associated with concrete scenarios are often analogically extended to more abstract concepts. Consider these sentences:

1. a. The messenger went from Paris to Istanbul.
- b. The inheritance went to Fred.
- c. The light went from green to red.
- d. The meeting went from 3:00–4:00.

The first sentence (a) uses the verb *go* and the prepositions *from* and *to* in their usual spatial senses, indicating the motion of an object from a source to a goal. But in 1(b), the words are used to indicate a *metaphorical* motion, as if wealth moved in space from owner to owner. In 1(c) the words are being used to express a change of state: a kind of motion in state-space. And in 1(d) they convey a shift in time, as if scheduling an event was placing or moving it along a time line.

A similar kind of extension may be seen in constructions expressing the use of force:

2. a. Rose forced the door to open.
- b. Rose forced Sadie to go.
- c. Rose forced herself to go.

2(a) conveys an instance of physical force, but 2(b) conveys a kind of metaphorical *interpersonal* force (a threat or wielding of authority), and 2(c) an *intrapersonal* force, as if the self were divided into agents and once part could restrain or impel another.

Tacit metaphors involving space and force are ubiquitous in human languages. Moreover, they participate in the combinatorial apparatus of grammar and thus can be assembled into more complex units. Many locutions concerning communication, for example, employ the complex metaphor of a sender (the communicator) putting an object (the idea) in a container (the message) and causing it to move to a recipient (the hearer or reader): *We gather* our ideas to *put* them *into* words, and if our words are not *empty* or *hollow*, we might *get* these ideas *across* to a listener, who can *unpack* our words to *extract* their *content* (62).

These metaphors could be, of course, nothing but opaque constructions coined in rare acts of creation by past speakers and memorized incomprehensibly by current ones. But several phenomena suggest that they reflect an ability of the human mind to readily connect abstract ideas with concrete scenarios. First, children occasionally make errors in their spontaneous speech,

which suggest they grasp parallels between space and other domains and extend them in metaphors they could not have memorized from their parents. Examples include *I putted part of the sleeve blue* (change of location → change of state), *Can I have any reading behind the dinner?* (space → time), and *My dolly is scrunched from someone . . . but not from me* (source of motion → source of causation) (63, 64). Second, several experiments have shown that when people are engaged in simple spatial reasoning it interferes with their thoughts about time and possession (9). Third, adults often experience episodes of spontaneous reminding in which an idea was activated only because it shared an abstract conceptual structure with the reminder, rather than a concrete sensory feature. For example, an episode of a barber not cutting a man's hair short enough may remind him of a wife not cooking his steak well enough done. A futile attempt at evenly darkening successive regions of a photo in Photoshop may remind a person of a futile attempt to level a wobbly table by successively cutting slices off each of its legs (9, 65, 66). This process of analogical reminding may be the real-time mental mechanism that allows cognitive structures for space, force, and other physical entities to be applied to more abstract subject matter.

The value of metaphorical abstraction consists not in noticing a poetic similarity but in the fact that certain logical relationships that apply to space and force can be effectively carried over to abstract domains. The position of an object in space is logically similar to the value of a variable, and thus spatial thinking can be co-opted for propositional inferences. In the realm of space, if one knows that A moves from X to Y, one can deduce that A is now at Y, but was not at Y in the past. An isomorphic inference may be made in the realm of possession: If A is *given* by Michael to Lisa, it is now *owned* by Lisa, but was not owned by her in the past.

A similar isomorphism allows reasoning about force to be co-opted for reasoning about abstract causation, because both support counterfactual inferences. If A forces B to move from X to Y, then if A had not forced it, B would still be at X. Similarly, if Michael forced Lisa to be polite to Sam, then if Michael had not forced her, she would not have been polite to Sam.

The value of a variable (which is parallel to position in space) and the causation of change (which is parallel to the application of force) are the basic elements of scientific thinking. This suggests that a mind that evolved cognitive mechanisms for reasoning about space and force, an analogical memory that encourages concrete concepts to be applied to abstract ones with a similar logical structures, and mechanisms of productive combination that assemble them into complex hierarchical data structures, could engage in the mental activity required for modern science (9, 10, 67). In this conception, the brain's ability to carry out metaphorical abstraction did not evolve to coin metaphors in language, but to multiply the opportunities for cognitive inference in domains other than those for which a cognitive model was originally adapted.

Evidence from science education and the history of science suggest that structured analogies and other mental reassignments in which a concrete domain of cognition is attached to a new subject matter are crucial to the discovery and transmission of scientific and mathematical ideas (8, 68–70). Children learn to extend their primitive number sense beyond "one, two, many" by sensing the analogies among an increase in approximate magnitude, position along a line, and the order of number words in the counting sequence. To learn chemistry, people must stretch their intuitive physics and treat a natural substance not as having an essence but as consisting of microscopic objects and connectors. To understand biology, they put aside the intuitive notions of essences and vital forces and think of living things the way they think of tools, with a function and structure. To learn psychology and neuroscience, they must treat the mind not as an immaterial soul but as the organ of a living creature, as an artifact designed by natural selection, and as a collection of physical objects, neurons.

Wallace, recall, also wondered about the human ability to participate in modern institutions such as governments, universities, and corporations. But like humans' puzzling ability to do science, their puzzling ability to take part in modern organizations is partly a pseudoproblem, because in fact the rules of modern institutions do not come naturally to us.

Sociality in natural environments is based on concepts and motives adapted to kinship, dominance, alliances, and reciprocity. Humans, when left to their own devices, tend to apply these mindsets within modern organizations. The result is nepotism, cronyism, deference to authority, and polite consensus—all of which are appropriate to traditional small-scale societies but corrosive of modern ones.

Just as successful science requires people to reassign their cognitive faculties in unprecedented ways, successful organizations require people to reassign their *social* faculties in evolutionarily unprecedented ways. In universities, for example, the mindset of communal sharing (which is naturally applied to food distribution within the family or village) must be applied to the commodity of ideas, which are treated as resources to be shared rather than, say, traits that reflect well on a person, or inherent wants that comrades must respect if they are to maintain their relationship. The evaluation of ideas also must be wrenched away from the mindset of authority: department chairs can demand larger offices or higher salaries but not that their colleagues and students acquiesce to their theories. These radically new rules for relationships are the basis for open debate and peer review in scholarship, and for the checks and balances and accounting systems found in other modern institutions (9).

Conclusion

The evolution of the human mind is such a profound mystery that it became the principal bone of contention between the two codiscoverers of the theory of natural selection. It has been an impetus to creationism and spiritualism in their day and in ours, and continues to be a source of proposed complications and elaborations of evolutionary theory. But in a year celebrating Darwin's life and work, it would be fitting to see if the most parsimonious application of his theory to the human mind is sufficient, namely that the mind, like other complex organs, owes its origin and design to natural selection.

I have sketched a testable theory, rooted in cognitive science and evolutionary psychology, that suggests that it is. According to this theory, hominids evolved to specialize in the cognitive niche, which is defined by: reasoning about the causal structure of the world, cooperating with other individuals, and sharing that knowledge and negotiating those agreements via language. This triad of adaptations coevolved with one another and with life-history and sexual traits such as enhanced parental investment from both sexes and multiple generations, longer childhoods and lifespans, complex sexuality, and the accumulation of local knowledge and social conventions in distinct cultures.

Although adaptations to the cognitive niche confer obvious advantages in any natural environment, they are insufficient for reasoning in modern institutions such as science and government. Over the course of history and in their own educations, people accommodate themselves to these new skills and bodies of knowledge via the process of metaphorical abstraction, in which cognitive schemas and social emotions that evolved for one domain can be pressed into service for another and assembled into increasingly complex mental structures.

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