HOW WE BECAME A DIFFERENT KIND OF ANIMAL

PART I

Why Us?

AN EVOLVED UNIQUENESS

BY KEVIN LALAND :: *ILLUSTRATION BY VICTO NGAI*

MOST PEOPLE ON THIS PLANET BLITHELY ASSUME, LARGELY without any valid scientific rationale, that humans are special creatures, distinct from other animals. Curiously, the scientists best qualified to evaluate this claim have often appeared reticent to acknowledge the uniqueness of *Homo sapiens,* perhaps for fear of reinforcing the idea of human exceptionalism put forward in religious doctrines. Yet hard scientific data have been amassed across fields ranging from ecology to cognitive psychology affirming that humans truly *are* a remarkable species.

IN BRIEF

Human accomplishments derive from our ability to acquire knowledge from others and to use that communal store of experience to devise novel solutions to life's challenges.

Other species innovate, too. Chimps open nuts with stone hammers. Dolphins use a tool to flush out hidden prey.

Our uniqueness has to do with a capacity to teach skills to others over the generations with enough precision for building skyscrapers or going to the moon.

The density of human populations far exceeds what would be typical for an animal of our size. We live across an extraordinary geographical range and control unprecedented flows of energy and matter: our global impact is beyond question. When one also considers our intelligence, powers of communication, capacity for knowledge acquisition and sharing—along with magnificent works of art, architecture and music we create—humans genuinely do stand out as a very different kind of animal. Our culture seems to separate us from the rest of nature, and yet that culture, too, must be a product of evolution.

The challenge of providing a satisfactory scientific explanation for the evolution of our species' cognitive abilities and their expression in our culture is what I call "Darwin's Unfinished Symphony." That is because Charles Darwin began the investigation of these topics some 150 years ago, but as he himself confessed, his understanding of how we evolved these attributes was in his own words "imperfect" and "fragmentary." Fortunately, other scientists have taken up the baton, and there is an increasing feeling among those of us who conduct research in this field that we are closing in on an answer.

The emerging consensus is that humanity's accomplishments derive from an ability to acquire knowledge and skills from other people. Individuals then build iteratively on that reservoir of pooled knowledge over long periods. This communal store of experience enables creation of ever more efficient and diverse solutions to life's challenges. It was not our large brains, intelligence or language that gave us culture but rather our culture that gave us large brains, intelligence and language. For our species and perhaps a small number of other species, too, culture transformed the evolutionary process.

The term "culture" implies fashion or haute cuisine, but boiled down to its scientific essence, culture comprises behavior patterns shared by members of a community that rely on socially transmitted information. Whether we consider automobile designs, popular music styles, scientific theories or the foraging of small-scale societies, all evolve through endless rounds of innovations that add incremental refinements to an initial baseline of knowledge. Perpetual, relentless copying and innovation—that is the secret of our species' success.

ANIMAL TALENTS

COMPARING HUMANS with other animals allows scientists to determine the ways in which we excel, the qualities we share with other species and when particular traits evolved. A first step to understanding how humans got to be so different, then, is to take this comparative perspective and investigate the social learning and innovation of other creatures, a search that leads ultimately to the subtle but critical differences that make us unique.

Many animals copy the behavior of other individuals and in this way learn about diet, feeding techniques, predator avoidance, or calls and songs. The distinctive tool-using traditions of different populations of chimpanzees throughout Africa is a famous example. In each community, youngsters learn the

FOLLOWING in the steps of others—social learning—has been a key to the success of *Homo sapiens* as long as it has existed as a separate species. Here members of the San group in Namibia walk the dunes single file.

local behavior—be it cracking open nuts with a stone hammer or fishing for ants with a stick—by copying more experienced individuals. But social learning is not restricted to primates, large-brained animals or even vertebrates. Thousands of experimental studies have demonstrated copying of behavior in hundreds of species of mammals, birds, fishes and insects. Experiments even show that young female fruit flies select as mates males that older females have chosen.

A diverse range of behaviors are learned socially. Dolphins possess traditions for foraging using sea sponges to flush out fish hiding on the ocean floor. Killer whales have seal-hunting traditions, including the practice of knocking seals off ice floes by charging toward them in unison and creating a giant wave. Even chickens acquire cannibalistic tendencies through social learning from other chickens. Most of the knowledge transmitted through animal populations concerns food—what to eat and where to find it—but there are also extraordinary social conventions. One troop of capuchin monkeys in Costa Rica has devised the bizarre habit of inserting fingers into the eye sockets or nostrils of other monkeys or hands into their mouths, sitting together in this manner for long periods and gently swaying—conventions that are thought to test the strength of social bonds.

Animals also "innovate." When prompted to name an innovation, we might think of the invention of penicillin by Alexander Fleming or the construction of the World Wide Web by Tim Berners-Lee. The animal equivalents are no less fascinating. My favorite concerns a young chimpanzee called Mike, whom primatologist Jane Goodall observed devising a noisy dominance display that involved banging two empty kerosene cans together. This exhibition thoroughly intimidated Mike's rivals and led to him shooting up the social rankings to become alpha male in record time. Then there is the invention by Japanese carrion crows of using cars to crack open nuts. Walnuts shells are too tough for crows to crack in their beaks, but they nonetheless feed on these nuts by placing them in the road for cars to run over, returning to retrieve their treats when the lights turn red. And a group of starlings—birds famously fond of shiny objects used as nest decorations—started raiding a coin machine at a car wash in Fredericksburg, Va., and made off with, quite literally, hundreds of dollars in quarters. [For further examples of how animals adjust to urban environments, see "Darwin in the City," on page 82.]

Such stories are more than just enchanting snippets of natural history. Comparative analyses reveal intriguing patterns in the social learning and innovation exhibited by animals. The most significant of these discoveries finds that innovative species, as well as animals most reliant on copying, possess unusually large brains (both in absolute terms and relative to body size). The correlation between rates of innovation and brain size was initially observed in birds, but this research has since been replicated in primates. These findings support a hypothesis known as cultural drive, first proposed by University of California, Berkeley, biochemist Allan C. Wilson in the 1980s.

KERSTIN GEIER *Getty Images*

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Wilson argued that the ability to solve problems or to copy the innovations of others would give individuals an edge in the struggle to survive. Assuming these abilities had some basis in neurobiology, they would generate natural selection favoring ever larger brains—a runaway process culminating in the huge organs that orchestrate humans' unbounded creativity and all-encompassing culture.

Initially scientists were skeptical of Wilson's argument. If fruit flies, with their tiny brains, could copy perfectly well, then why should selection for more and more copying generate the proportionately gigantic brains seen in primates? This conundrum endured for years, until an answer arose from an unexpected source.

COPYCATS

THE SOCIAL LEARNING STRATEGIES TOURNAMENT was a competition that my colleagues and I organized that was designed to work out the best way to learn in a complex, changing environment. We envisaged a hypothetical world in which individuals—or agents as they are called—could perform a large number of possible behaviors, each with its own characteristic payoff that changed over time. The challenge was to work out which actions would give the best returns and to track how these changed. Individuals could either learn a new behavior or perform a previously learned one, and learning could occur through trial-and-error or through copying other individuals. Rather than trying to solve the puzzle ourselves, we described the problem and specified a set of rules, inviting anyone interested to have a go at solving it. All the entries—submitted as software code that specified how the agents should behave—competed against one another in a computer simulation, and the best performer won a €10,000 prize. The results were highly instructive. We found a strong positive relation between how well an entry performed and how well it required agents to learn socially. The winning entry did not require agents to learn often, but when they did, it was almost always through copying, which was always performed accurately and efficiently.

Brains are energetically costly organs, and social learning is paramount to animals that need to gather the resources necessary to grow and maintain a large brain efficiently.

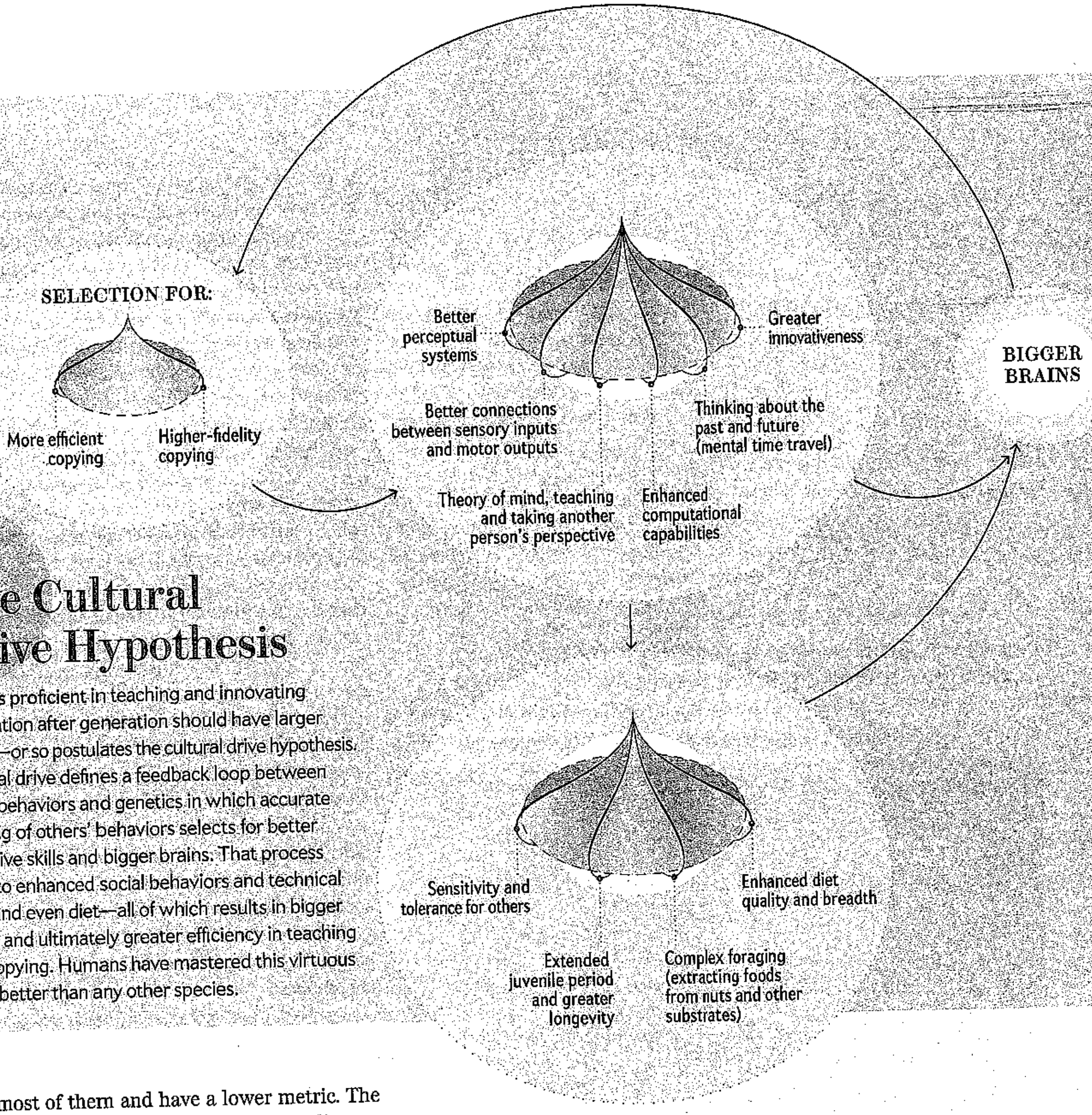
The tournament taught us how to interpret the positive relation between social learning and brain size observed in primates. The results suggested that natural selection does not favor more and more social learning but rather a tendency toward better and better social learning. Animals do not need a big brain to copy, but they do need a big brain to copy well.

This insight stimulated research into the empirical basis of the cultural drive hypothesis. It led to the expectation that natural selection ought to favor anatomical structures or functional capabilities in the primate brain that promote accurate, efficient copying. Examples might include better visual perception if that allows copying over greater distances or imitating fine-motor actions. In addition, selection should foster greater connections between perceptual and motor structures in the brain, helping individuals to translate the sight of others performing a skill into their producing a matching performance by moving their body in a corresponding way.

The same cultural drive hypothesis also predicted that selection for improved social learning should have influenced other aspects of social behavior and life history, including living in social groups and using tools. The reasoning was that the bigger the group and the more time spent in the company of others, the greater the opportunities for effective social learning. Through copying, monkeys and apes acquire diverse foraging skills ranging from extractive foraging methods such as digging grubs out of bark to sophisticated tool-using techniques such as fishing for termites with sticks. If social learning is what allows primates to pick up difficult-to-learn but productive food-procurement methods, any species proficient in social learning should show elevated levels of extractive foraging and tool use. They should possess a richer diet and have longer lives, if that gives more time for learning new skills and passing them on to descendants. In sum, cultural drive predicts that rates of social learning will correlate not only with brain size but also with a host of measures related to cognitive performance.

Rigorous comparative analyses have borne out these predictions. Those primates that excel at social learning and innovation are the same species that have the most diverse diets, use tools and extractive foraging, and exhibit the most complex social behavior. In fact, statistical analyses suggest that these abilities vary in lockstep so tightly that one can align primates along a single dimension of general cognitive performance, which we call primate intelligence (loosely analogous to IQ in humans).

Chimpanzees and orangutans excel in all these performance measures and have high primate intelligence, whereas some nocturnal prosimians are



The Cultural Drive Hypothesis

Species proficient in teaching and innovating generation after generation should have larger brains—or so postulates the cultural drive hypothesis. Cultural drive defines a feedback loop between social behaviors and genetics in which accurate copying of others' behaviors selects for better cognitive skills and bigger brains. That process leads to enhanced social behaviors and technical skills and even diet—all of which results in bigger brains and ultimately greater efficiency in teaching and copying. Humans have mastered this virtuous circle better than any other species.

poor at most of them and have a lower metric. The strong correlations between primate intelligence and both brain size measures and performance in laboratory tests of learning and cognition validate the use of the metric as a measure of intelligence. The interpretation also fits with neuroscientific analyses showing that the size of individual brain components can be accurately predicted with knowledge of overall brain size. Associated with the evolution of large primate brains are bigger and better-connected regions—neocortices and cerebellums—that allow executive control of actions and increased cortical projections to the motor neurons of the limbs, facilitating controlled and precise movements. This helps us to understand why big-brained animals show complex cognition and tool use. [For more on primate brains, see "Are We Wired Differently?" on page 60.]

Plotting the intelligence measure on a primate family tree reveals evolution for higher intelligence taking place independently in four distinct primate groups: the capuchins, macaques, baboons and great apes—precisely those species renowned for their social learning and traditions. This finding is exactly the pattern expected if cultural processes really were driving the evolution of brain and cognition. Further analyses, using better data and cutting-edge statistical methods, reinforce these conclusions, as do models that make quantitative predictions for brain and body size based on estimates of the brain's metabolic costs.

Cultural drive is not the only cause of primate brain evolution: diet and sociality are also important because fruit-eating primates and those living in large, complex groups possess large brains. It is difficult, however, to escape the conclusion that high intelligence and longer lives co-evolved in some primates because their cultural capabilities allowed them to exploit high-quality but difficult-to-access food resources, with the nutrients gleaned "paying" for brain growth. Brains are energetically costly organs, and social learning is paramount to animals gathering the resources necessary to grow and maintain a large brain efficiently.

Graphic by Federica Fragapane

NO CHIMP MOBILES

WHY, THEN, DON'T OTHER PRIMATES have complex culture like us? Why haven't chimpanzees sequenced genomes or built space rockets? Mathematical theory has provided some answers. The secret comes down to the fidelity of information transmission from one member of a species to another, the accuracy with which learned information passes between transmitter and receiver. The size of a species' cultural repertoire and how long cultural traits persist in a population both increase exponentially with transmission fidelity. Above a certain threshold, culture begins to ratchet up in complexity and diversity. Without accurate transmission, cumulative culture is impossible. But once a given threshold is surpassed, even modest amounts of novel invention and refinement lead rapidly to massive cultural change. Humans are the only living species to have passed this threshold.

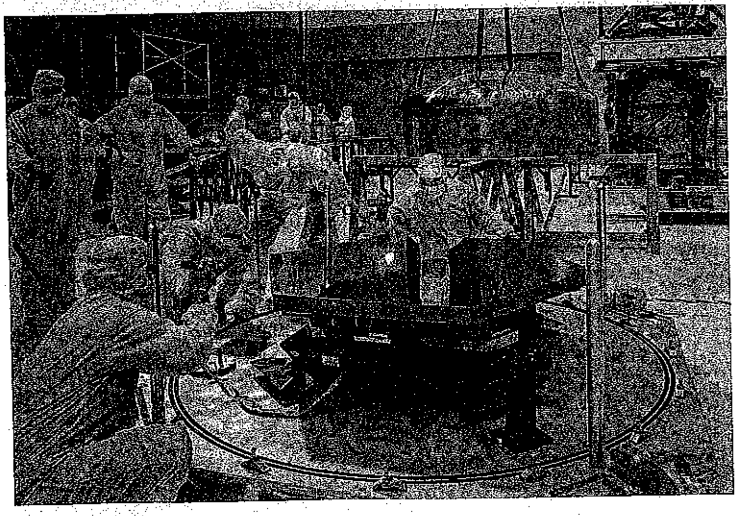
Our ancestors achieved high-fidelity transmission through teaching—behavior that functions to facilitate a pupil's learning. Whereas copying is widespread in nature, teaching is rare, and yet teaching is universal in human societies once the many subtle forms this practice takes are recognized. Mathematical analyses reveal tough conditions that must be met for teaching to evolve, but they show that cumulative culture relaxes these conditions. The modeling implies that teaching and cumulative culture co-evolved in our ancestors, creating for the first time in the history of life on our planet a species whose members taught their relatives a broad range of skills, perhaps cemented through goal-oriented "deliberate" practice [see "Inside Our Heads," on page 42].

The teaching of cultural knowledge by hominins (humans and their extinct close relatives) included foraging, food processing, learned calls, toolmaking, and so forth and provided the context in which language first appeared. Why our ancestors alone evolved language is one of the great unresolved questions. One possibility is that language developed to reduce the costs, increase the accuracy and expand the domains of teaching. Human language may be unique, at least among extant species, because only humans constructed a sufficiently diverse and dynamic cultural world that demanded talking about. This explanation has the advantage that it accounts for many of the characteristic properties of language, including its distinctiveness, its power of generalization and why it is learned [see "Talking through Time," on page 54].

Language began as just a handful of shared symbols. But once started, the use of protolanguage imposed selection on hominin brains for language-learning skills and on languages themselves to favor easy-to-learn structures. That our ancestors' cultural activities imposed selection on their bodies and minds—a process known as gene culture co-evolution—is now well supported. Theoretical, anthropological and genomic analyses all demonstrate how socially transmitted knowledge, including that expressed in the manufacture and use of tools, generated natural selection that transformed human anatomy and cognition. This evolutionary feedback shaped the emergence of the modern human mind, generating an evolved psychology that spurred a motivation to teach, speak, imitate, emulate, and share the goals and intentions of others. It also produced enhanced learning and computational abilities. These capabilities evolved with cumulative culture because they enhance the fidelity of information transmission.

Teaching and language were evolutionary game changers for our lineage. Large-scale cooperation arose in human societies because of our uniquely

CHIMPS AND HUMANS are both toolmakers. Chimpanzees use sticks to hunt for a meal of termites and pass this technique along to their kin. Unlike chimps, humans transmit cultural knowledge to offspring with a high degree of precision that enables the making of sophisticated technologies.



STEVE BLOOM *Alamy (chimpanzees)*; CHRIS GUNN NASA *(telescope mirror)* potent capacities for social learning and teaching, as theoretical and experimental data attest. Culture took human populations down novel evolutionary pathways, both by creating conditions that promoted established mechanisms for cooperation witnessed in other animals (such as helping those that reciprocate) and by generating novel cooperative mechanisms not seen elsewhere. Cultural group selection—practices that help a group cooperate and compete with other groups (forming an army or building an irrigation system)—spread as they proved their worth [see "The Origins of Morality," on page 70].

Culture provided our ancestors with food-procurement and survival tricks, and as each new invention arose, a given population was able to exploit its environment more efficiently. This occurrence fueled not only brain expansion but population growth as well. Increases in both human numbers and societal complexity followed our domestication of plants and animals. Agriculture freed societies from the constraints that the peripatetic lives of hunter-gatherers imposed on population size and any inclinations to create new technologies. In the absence of this constraint, agricultural societies flourished, both because they outgrew hunter-gatherer communities through allowing an increase in the carrying capacity of a particular area for food production and because agriculture triggered a raft of associated innovations that dramatically changed human society. In the larger societies supported by increasing farming yields, beneficial innovations were more likely to spread and be retained. Agriculture precipitated a revolution not only by triggering the invention of related technologies—ploughs or irrigation technology, among others—but also by spawning entirely unanticipated initiatives, such as the wheel, city-states and religions.

The emerging picture of human cognitive evolution suggests that we are largely creatures of our own making. The distinctive features of humanity—our intelligence, creativity, language, as well as our ecological and demographic success—are either evolutionary adaptations to our ancestors' own cultural activities or direct consequences of those adaptations. For our species' evolution, cultural inheritance appears every bit as important as genetic inheritance.

We tend to think of evolution through natural selection as a process in which changes in the external environment, such as predators, climate or disease, trigger evolutionary refinements in an organism's traits. Yet the human mind did not evolve in this straightforward way. Rather our mental abilities arose through a convoluted, reciprocal process in which our ancestors constantly constructed niches (aspects of their physical and social environments) that fed back to impose selection on their bodies and minds, in endless cycles. Scientists can now comprehend the divergence of humans from other primates as reflecting the operation of a broad array of feedback mechanisms in the hominin lineage. Similar to a self-sustaining chemical reaction, a runaway process ensued that propelled human cognition and culture forward. Humanity's place in the evolutionary tree of life is beyond question. But our ability to think, learn, communicate and control our environment makes humanity genuinely different from all other animals. ■

A Visit from E.T.

Imagine an extraterrestrial intelligence studying Earth's biosphere. Which of all the species would it identify as differing from the rest? The answer is humanity. Here are a few reasons:

Population size. Our numbers are out of kilter with global patterns for vertebrate populations. There are several orders of magnitude more humans than expected for a mammal of our size.

Ecological range. Our species distribution is extraordinary. Humans have colonized virtually every region of the terrestrial globe.

Environmental regulation. Humans control vast and diverse flows of energy and matter on unprecedented scales.

Global impact. Human activities threaten and are driving extinct unmatched numbers of species while eliciting strong evolutionary change across the biosphere.

Cognition, communication and intelligence. Experiments demonstrate superior performance by humans across diverse tests of learning and cognition. Human language is infinitely flexible, unlike the communication of other animals.

Knowledge acquisition and sharing. Humans acquire, share and store information on never-before-seen scales and build on their pooled cultural knowledge cumulatively from generation to generation.

Technology. Humans invent and mass-produce infinitely more complex and diverse artifacts than other animals.

The extraterrestrials might well be charmed by the elephant's trunk and impressed by the giraffe's neck, but it is humans that they would single out. —*K.L.*

MORE TO EXPLORE

Social Intelligence, Innovation, and Enhanced Brain Size in Primates. Simon M. Reader and Kevin N. Laland in *Proceedings of the National Academy of Sciences USA*, Vol. 99, No. 7, pages 4436–4441; April 2, 2002.

Why Copy Others? Insights from the Social Learning Strategies Tournament. L. Rendell et al. in *Science*, Vol. 328, pages 208–213; April 9, 2010.

Identification of the Social and Cognitive Processes underlying Human Cumulative Culture. L. G. Dean et al. in *Science*, Vol. 335, pages 1114–1118; March 2, 2012.

FROM OUR ARCHIVES

The Morning of the Modern Mind. Kate Wong; June 2005.

scientificamerican.com/magazine/sa

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HY ARE WE, AND NOT THE GORILLAS, RUNNING THE ZOOS?

Other primates live inconspicuously in dwindling habitats, but humans have expanded and changed our surroundings to an astounding degree. Our dominance is obviously not the result of our physical ability; other animals are stronger and faster and have more acute senses. It is because of our mental abilities. Yet determining the cognitive traits that make us so special has turned out to be a devilishly complicated question to answer—one made more confusing by the frequent arrival of new studies that seem to show that animals from birds to chimpanzees can match many human cognitive skills.

Last year, to name just one example, a study published in *Science* boldly claimed that ravens can plan for the future just like humans do. Five birds learned to pick a stone and drop it into a box to get a reward. Subsequently, these ravens picked the rock from among distracting items minutes or even hours before the box was available to them. The researchers concluded from this achievement, along with a similar task in which the birds could exchange bottle tops for rewards, that the ravens were "thinking ahead" in flexible ways, an ability that is a key to human brainpower.

Yet the achievements of the ravens, as well as cognitive feats of apes in other studies, can be explained in simpler ways. It also turns out that animal and human cognition, though similar in many respects, differ in two profound dimensions. One is the ability to form nested scenarios, an inner theater of the mind that allows us to envision and mentally manipulate many possible situations and anticipate different outcomes. The second is our drive to exchange our thoughts with others. Taken together, the emergence of these two characteristics transformed the human mind and set us on a world-changing path.

IN BRIEF

Humans clearly think differently than animals, but experiments that show *how* human cognition is unique have been hard to do.

Yet research has revealed two distinct human features: complex scenario building and exchanging thoughts with others.

Together these traits underlie critical human capacities such as language, culture, morality, foresight and even a kind of "mind reading."

BIRD BRAINS

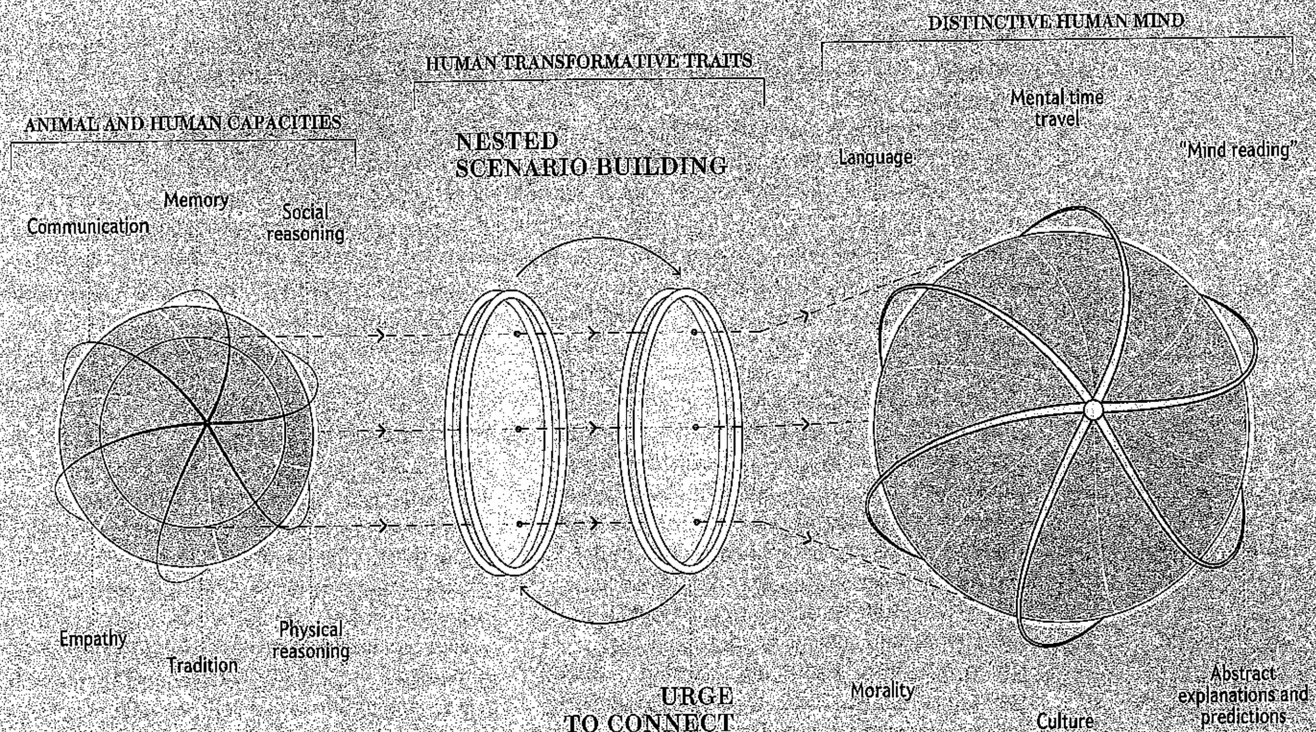
LET US BEGIN by taking a harder look at that raven experiment. Even before the tests started, the birds had learned, over several trials, to recognize that the target item, the stone, led to rewards and that distractor items did not. So it is not really surprising that when the actual trials began, the ravens selected what had already been reinforced.

This is a good reason why scientists, before they jump to conclusions about "rich" animal capacities, need to carefully rule out more straightforward, or "lean," alternative explanations. They also need to conduct independent replications. In my laboratory, we have tried to do this by conducting studies with children that carefully limit the possibility of mistaking behavior actually driven by lean mechanisms for the products of rich cognition. We used single trials with novel tasks on our subjects to avoid giving them the learning opportunities that occur through repeated exposure. We also changed up the timing and spatial contexts of the tests to avoid cueing the children about the solution, and we concocted problems that involved the use of different skills to mitigate the effects of behavior that may result from a narrow innate predisposition.

For example, we showed the youngsters a puzzle box in one room before taking them to another room in which they were distracted with unrelated tasks. After 15 minutes, they were given the opportunity to pick one of several novel objects to take back to the first room. The three-year-olds picked randomly, but the four-year-olds tended to select the object that could later help solve the puzzle they were initially given. We have used this basic paradigm to assess the capacity for deliberate practice, which is the rehearsal of actions aimed at improving future performance [see "An Evolved Uniqueness," on page 32]. For instance, the children had the opportunity to practice catching a ball on a string with a cup in preparation for a return to the first room, where they could get a reward for success in a similar task.

Two Transformational Traits

Research in comparative psychology has identified several cognitive capacities shared by animals and humans, in domains such as communication, memory, social reasoning, physical reasoning, tradition and empathy. But two unique human features helped transform these capacities into abilities of the mind that set us apart from the animal world. One feature, nested scenario building, allows us to imagine several alternative situations, some with different outcomes, and embed them into a larger narrative of connected events. The second feature is the urge to connect, the human drive to exchange thoughts with others, enabling achievements beyond the abilities of lone individuals. These two traits amplify each other and have altered our minds, leading to human language, mental time travel, morality, culture, "mind reading" (or discerning the thoughts of others), and the capacity to develop and share abstract explanations of the world around us.



We found that the children could intentionally shape their own future abilities—they would practice the relevant skill in room two—after around age four or five but not before.

These tasks are designed to show basic capacities in areas such as foresight, and they do not map the upper limits of those abilities. When my son was four years old, for instance, we gave him a version of this task, and he succeeded. Later that day, when we were sitting on the bed back home, he put his hand on my thigh and said, "Papa, I don't want you to die." When I asked why he thought of that, he said that he would grow up, and I would become a granddad, and then I would die. He had a sophisticated capacity for envisioning the future that produced this unwelcome existential realization. Our study merely demonstrated that he had mental foresight and ruled out the leaner explanations.

The raven research and other animal studies have not met similar stringent criteria for establishing foresight, nor have they demonstrated deliberate practice. Does this mean we should conclude that animals do not have the relevant capacities at all? That would be premature. Absence of evidence is not evidence of absence, as the saying goes. Establishing competence in animals is difficult; establishing the absence of competence is even harder.

Consider the following study, in which my colleague Jon Redshaw of the University of Queensland in Australia and I tried to assess one of the most fundamental aspects of thinking about the future: the recognition that it is largely uncertain. When one realizes that events may unfold in more than one way, it makes sense to prepare for various possibilities and to make contingency plans. Human hunters demonstrate this when they lay a trap in front of all their prey's potential escape routes rather than just in front of one. Our simple test of this capacity was

Graphic by Federica Fragapane

to show a group of chimpanzees and orangutans a vertical tube and drop a reward at the top so they could catch it at the bottom. We compared the apes' performance with that of a group of human children aged two to four doing the same thing. Both groups readily anticipated that the reward would reappear at the bottom of the tube: they placed their hand under the exit to prepare for the catch.

Next, however, we made events a little harder to predict. The straight tube was replaced by an upside-down Y-shaped tube that had two exits. In preparation for the drop, the apes and the two-year-old children alike tended to cover only one of the potential exits and thus ended up catching the reward in only half of the trials. But four-year-olds immediately and consistently covered both exits with their hands, thus demonstrating the capacity to prepare for at least two mutually exclusive versions of an imminent future event. Between ages two and four, we could see this contingency planning increase in frequency. We saw no such ability among the apes.

This experiment does not prove, however, that apes and two-year-old humans have no understanding that the future can unfold in distinct ways. As I mentioned, there is a fundamental problem when it comes to showing the absence of a capacity. Perhaps the animals were not motivated, did not understand the basic task or could not coordinate two hands. Or maybe we simply tested the wrong individuals, and more competent animals might be able to pass.

To truly prove this ability is absent, a scientist would have to test all animals, at all times, on some fool-proof task. Clearly, that is not practical. All we can do is give individuals the chance to demonstrate competence. If they consistently fail, we can become more confident that they really do not have the capacity in question, but even then, future work may prove that wrong. The debates between rich and lean interpretations of animal behavior, coupled with this fundamental problem of proving that an ability is always missing, have made it difficult to establish what does and does not set humans apart.

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MIND THE GAP

DIFFICULT BUT NOT IMPOSSIBLE. In my book *The Gap: The Science of What Separates Us from Other Animals,* I surveyed the evidence for cognitive capacities most frequently assumed to be distinctly human and found that animals are smarter than widely thought. For instance, chimpanzees can solve problems through insight, console others in distress and maintain social traditions. Nevertheless, there is something profoundly distinct about human language, foresight, intelligence, culture and morality, and the ability to imagine the thoughts of another individual (we commonly speak about putting yourself in someone else's shoes). And in each of these domains, two underlying characteristics kept reemerging as making the critical human-animal difference. One is what I call "nested scenario building," which is our ability to imagine alternative situations, reflect on them and embed them into larger narratives of related events. The other is the "urge to connect," which is our deep-seated drive and capacity to exchange our thoughts with others, when we put our minds together to create something greater than what one individual can do alone.

Nested scenario building enables us to imagine other people's situations, moral conundrums or entirely fictional stories. In the context of thinking ahead, it allows us to picture potential future events, reflect on possibilities and embed them into larger stories of unfolding events. This, in turn, enables us to plan and prepare for opportunities and threats before they materialize.

Other animals, even bacteria, are attuned to long-term regularities such as day-night rhythms, and many can adjust to local patterns as well. Through associative learning, animals can predict that a reward or punishment is coming after a specific event. But people can mentally entertain situations, even entirely novel scenarios without external triggers, by combining and recombining in our mind basic elements, such as actors, actions and objects, and we can draw prudent conclusions from these mental exercises. A simple example: you can picture playing blindman's bluff on a busy street and figure out that it is a dangerous proposition even if you have never been in that situation. Nested scenario building depends on a host of sophisticated abilities working in concert, including imagination, memory, reflection and executive decision making.

Think of creating nested scenarios as an internal theater in which we can bring situations to life. Like a play, scenario building depends on certain components that have to come together. There is a "stage" to imagine events that are not actually occurring at that moment. Those events involve "actors" and their "set": individuals and objects that are linked in a narrative. We also employ capacities akin to a "director" who evaluates and manages the scenes and an "executive producer" who makes the final decisions about what to pursue. These components map onto psychological constructs such as working memory, recursive thought and executive function, features that develop at different rates during human childhood. As a result, competence at foresight emerges slowly as we mature. And as adults, we still frequently fail to anticipate future situations accurately—I most certainly do. We are not clairvoyants.

Thus, because nested scenario building is a risky way to reach decisions, humans need to pair it with that second characteristic: connecting our minds. Psychologist Michael Tomasello has described this ability as shared intentionality [see "The Origins of Morality," on page 70]. After all, the best way to find out about the future is to ask someone who has already been there, as it were.

If you really want to know what a holiday in New Zealand is like or what a career in psychology entails, you can envision all the scenarios you want, but your best bet is to ask someone who has been to that country or has pursued such a career. Human language is ideally suited for such exchanges; most of our conversations are about events displaced in time. In this way, we can learn from one another's experiences, reflections and plans. We ask questions and give advice, and we build deep bonds in the process. What is more, we can also shape the future in more deliberate ways by coordinating our actions in the pursuit of shared goals. We often do this by commenting on a companion's strategy, reviewing progress and then guiding the person to the next step.

Most of our extraordinary powers, when you think about it, derive from our collective wit. Consider that we all benefit from the tools and technologies other people invented. Many animals use tools, and some even make them, but to turn them into an innovation, one has to recognize that it will be useful again in the future. After that realization, one has a reason to retain the tool, to refine it further and to share it with others.

We can see this evolution in our inventions of increasingly effective ways to cause harm at a distance. This was probably a vital capacity for our early ancestors, who shared the land with dangerous saber-toothed cats. At first, our progenitors may have thrown rocks to drive away predators, but eventually they armed themselves with spears, then invented spear throwers, and then bows and arrows. New tools are only an advance, however, if one can use them effectively, which brings us back to deliberate practice. Chimpanzees in Senegal have been reported to make rudimentary spears that they thrust into tree hollows to kill bush babies. But there is as yet no observation that they practice thrusting, let alone throwing. Unlike humans, they could not benefit from the invention of a spear thrower. You can safely give them one of ours; they would not use it as we do.

The earliest evidence of deliberate practice is more than a million years old. The Acheulean stone tools of *Homo erectus* some 1.8 million years ago already suggest considerable foresight, as they appeared to have been carried from one place to another for repeated use. Crafting these tools requires considerable knowledge about rocks and how to work them. At some sites, such as Olorgesailie in Kenya, the ground is still littered with shaped stones, raising the question of why our ancestors kept making more tools when there were plenty lying around. The answer is that they were probably practicing how to manufacture those tools. Once they were proficient, they could wander the plains knowing they could make a new tool if the old one broke. These ancestors were armed and ready to reload.

Most animal species can be categorized as either specialists or generalists, but humans are both: we are capable of quickly adapting to local demands, even to anticipated demands, by acquiring relevant expertise. Moreover, through cooperation and division of labor, we can benefit from complementary skills, thereby enabling us to dominate most diverse habitats. We can keep even the fiercest predators in our zoos because we can foresee what they need and what they can and cannot do. So far there is no obvious evidence of other species engaging in such mental time travel nor in exchanging plots for a coordinated escape from the zoo when the conditions are right next summer.

With nested scenario building and the urge to wire their minds together, our ancestors eventually spawned civilizations and technologies that have changed the face of the earth. Science is the disciplined use of our collective wit, and we can deploy it to better understand the origin of our place in nature. We can further use it to model the future systematically and ever more clearly. By foreseeing the consequences of our actions, we are also confronted with moral choices between different options. We can predict the consequences of continuing pollution or destruction of animal habitats, inform others about them and, as the Paris climate agreement dramatically demonstrates, negotiate globally coordinated actions aimed at more desirable outcomes.

None of this is an excuse for arrogance. It is, in fact, a call for care. We are the only creatures on this planet with these abilities. As Spider-Man's Uncle Ben declared, communicating complex ideas in an urge to connect with his superhero nephew, "With great power comes great responsibility." ■

MORE TO EXPLORE

The Gap: The Science of What Separates Us from Other Animals. Thomas Suddendorf. Basic Books, 2013.

A Natural History of Human Thinking. Michael Tomasello. Harvard University Press, 2014.

Flexible Planning in Ravens? Jonathan Redshaw, Alex H. Taylor and Thomas Suddendorf in *Trends in Cognitive Sciences,* Vol. 21, No. 11, pages 821–822; November 2017.

Prospection and Natural Selection. T. Suddendorf, A. Bulley and B. Miloyan in *Current Opinion in Behavioral Sciences,* Vol. 24, pages 26–31; December 2018.

FROM OUR ARCHIVES

If I Had a Hammer. Ian Tattersall; September 2014.

scientificamerican.com/magazine/sa