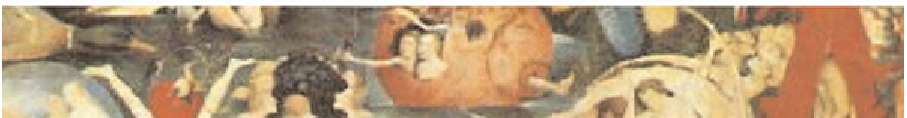
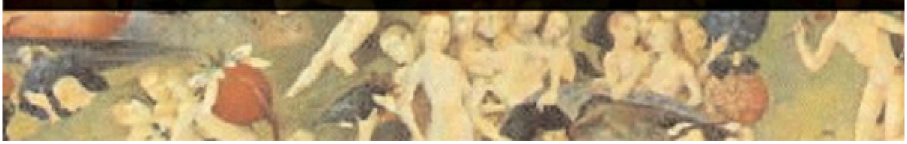
INTELLIGENCE IN NATURE

AN INQUIRY INTO KNOWLEDGE



JEREMY NARBY

AUTHOR OF *The Cosmic Serpent*



Intelligence in Nature

ALSO BY JEREMY NARBY

The Cosmic Serpent: DNA and the Origins of Knowledge

Shamans Through Time: 500 Years on the Path to Knowledge (with Francis Huxley)

Intelligence in Nature

AN INQUIRY INTO KNOWLEDGE

Jeremy Narby

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To Beatrice

AUTHORâ ™S NOTE

The endnotes tell a story of their own, and I leave it to individual readers to determine how much or how little to use them. The narrative can be read entirely by itself, but for those who wish more information on a given topic or statement, many passages are calibrated by chapter, page number, and subject matter to endnotes that begin on page 149.

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NATURE LOVES TO HIDE

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HERACLITUS

INTELLIGENCE IN NATURE

Introduction

Searching for Intelligence in Nature

For fifteen years I have helped indigenous Amazonian people gain titles to their lands. These are people who believe that plants and animals have intentions, and that shamans communicate with other species in visions and dreams. Their way of knowing is difficult for rationalists to grasp.

More than a decade ago, I began searching for common ground between indigenous knowledge and Western science, and ended up finding links between shamanism and molecular biology. In the book *The Cosmic Serpent,* I presented the hypothesis that shamans take their consciousnesses down to the molecular level and gain access in their visions to information related to DNA, which they call â œanimate essences,â or â œspirits.â

In the Amazon, indigenous leaders and shamans expressed broad interest and support for this approach. For them, it was not news that their knowledge is real.

But on the other side of the equation, things were more complicated. Western science has some difficulty with the possibility of both nonhuman intelligence and the subjective acquisition of objective knowledge. Since its original publication in 1995, *The Cosmic Serpent* has not gained the attention I had hoped for from scientists. However, several biologists read it with interest and engaged me in dialogue. One biophysicist challenged me to test the hypothesis, saying that this was the true method of science.

He had a point. As an anthropologist, I am no scientist and had never tested a hypothesis. I decided to take up this challenge. To test the hypothesis, I accompanied three molecular biologists to the Peruvian Amazon to see whether they could obtain biomolecular information by ingesting a psychoactive plant brew administered by an indigenous shaman. In the realm of visions, all three received clear answers about their work.

One of these molecular biologists, Dr. Pia Malnoe, who teaches at a Swiss University and who directs a research laboratory, concluded: â œThe way shamans get their knowledge is not very different from the way scientists get their knowledge. It has the same origin, but shamans and scientists use different methods.â

I published an account of this encounter between parallel avenues of human knowledge and ultimately realized I was stuck on getting the approval of the scientific establishment. I decided to redirect my inquiry.

One question seemed more important than any other. By digging into history, mythology, indigenous knowledge, and science, I had found clues pointing to intelligence in nature. This seemed like a new way of looking at living beings. I had grown up in the suburbs and received a materialist and rationalist educationâ ”a worldview that denies intention in nature and considers living beings as â œautomatonsâ and â œmachines.â But now, there was increasing evidence that this is wrong, and that nature teems with intelligence. Even the cells in our own bodies seem to harbor a hive of deliberate activity.

Toward the end of the 1990s I began focusing on the works of biologists who study organisms rather than molecules. To my surprise I found a number of recent studies demonstrating that even simple creatures behave with intelligence. Scientists now show that brainless single-celled slime molds can solve mazes and bees with brains the size of pinheads can handle abstract concepts. Philosopher John Locke proclaimed in the seventeenth century: â œBrutes abstract not.â But, in fact, brutes abstract, and reductionist science recently proved it. I even found contemporary scientists who claim that natural beings can only be understood by attributing humanness to them. This is what shamans have been saying all along.

This led me to launch an investigation on the subject of â œintelligence in nature,â a concept constructed by combining science and indigenous knowledge. I would later learn that Japanese researchers already possess a term for this â œknowingnessâ of the natural world: *chi-sei* (pronounced CHEE-SAY). But I would begin the first leg of my search in the Amazon, where I had first met people who attribute spirits, intentions, and humanness to other species. Then I intended to do an anthropology of science and visit scientists in their working environment.

I set off on a quest not knowing what I was going to find. I went hunting for treasure, whereabouts unknown.

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ONE SUMMER DAY just before the beginning of this investigation I visited an old herbal healer living on an isolated farm in Estonia. Her name was Laine Roht, which means â œWave Grassâ in Estonian.

I was introduced to Roht by the Estonian translator of my previous book. She led us to a small outdoor shelter at the back of her garden, which contained a rudimentary fireplace decorated with empty Russian champagne bottles. Roht spoke only Estonian.

I explained that I was an anthropologist and wanted to ask her some questions. Roht nodded her consent. She sat upright on a bench, with her two hands joined together on her lap. I started by asking if she could explain how she had become a healer. She said her great-uncle was a healer, and that she was born with the gift. She said that plants speak to her, telling her when they are most potent and when to pick them; this sometimes happens at night, while she is resting; she receives instructions, gets up, and goes to the plants she has just been told about. The information she receives is always correct, she said. And when people tell her of their illness, she feels the sickness in her own body, which acts as a mirror. Later, when she learns which plants will heal the illness, she feels relief in the part of her body that has the empathy with the sick person. She did not elaborate on how she receives instructions from or about plants.

Her views reminded me of the notions held by some Amazonian shamans I had met. I decided to go straight to the point and asked what she could tell me about natureâ ™s intelligence. She shook her head, and said: â œNobody has asked me this before. It is difficult to penetrate nature. I have no words for it. There will never be such words. No one will ever know how plants and humans are made, or what will become of them. This will remain a secret.â

I found her pale blue gaze hard to sustain. When she spoke, I could listen only to the melody of her voice. Estonian is not an Indo-European language, and I found it difficult to make out a single word. When she paused, I listened to the translation and noted word by word what she had said. *See jÃ¤Ã¤b saladuseks. This will remain a secret.* The word *saladus* means secret.

I asked her why nature likes to hide. She replied: â œWe will get punished for giving away natureâ ™s secrets. You should not know everything. You should deal in a proper way with knowledge, heal people and treat them well. Secrets can fall into the hands of the wrong people.â

Her reply did not make me feel like prying any further.

She showed us around her garden and pointed to the plants she used to cure different conditions. We were reaching the end of the encounter. I felt moved to thank her for her time and consideration and went to the car to fetch a copy of my book in Estonian. The book has a serpent on its cover. She accepted it with both hands, glanced at the cover, and said: â œI have something for you.â

We followed her over to the main house and waited outside. She soon returned with a large glass jar containing alcohol distilled from the fruits of her garden and a dead viper. She explained that she had caught the viper in her garden several months ago and had dropped it into the alcohol while it was still alive. On expiring, the snake expelled its venom into the mixture, which, she said, would give us vitality and protect us from illness. She filled a shot glass with snake medicine and offered it to me. I knocked it back in the name of anthropology. It did not taste so bad. The first effect was a tingling warmth and a diffuse sense of well-being that seemed unrelated to the small amount of alcohol in the dose she had administered.

We thanked her once again and took our leave. I drove the return road in a state of grace, and during the weeks that followed, I felt glowing and full of energy. Once I returned home to Switzerland, people around me remarked on my good form. By telling this story, I am not trying to convince anybody of the efficacy of this particular batch of â œsnake oilâ (though more research would be interesting if only because snake venoms tend to contain substances that act on neurons). What really remained engraved in my mind were Laine Rohtâ ™s words. *This will remain a secret.* Did this mean I should not investigate natureâ ™s intelligence?

I turned these words over in my mind for months. I did not want to break into natureâ ™s box of secrets, but I did want to locate it and consider it from different angles. I traveled to the Amazon and met with indigenous people, then visited science laboratories in different countries. I found that science is coming closer to indigenous knowledge on certain levels. Science now shows that humans are fully related to other species. We are built like them and have brains like them. It also shows that other species are clever in their own ways. Still, Laine Rohtâ ™s words remained at the back of my mind. Was I up to no good? Was my investigation doomed to failure?

About a year and a half after visiting Laine Roht, it dawned on me that if something is destined to remain secret, then trying to find out about it is not problematic. Perhaps Laine Roht is right, and no one will ever understand how plants and people are made. But trying to gain knowledge about how nature knows is no crime. True, knowledge can be abused. But if nature has knowledge and I am part of nature, why should I not aim for knowledge?

Chapter 1

Brainy Birds

One day in September 2001 I boarded a canoe piloted by a Matsigenka Indian and began heading down the Urubamba River. We made our way through gorges filled with colorful parrots and other birds. The forests and rivers in this part of the Peruvian Amazon contain more species of trees, insects, reptiles, amphibians, birds, and mammals than any other region of similar size. We were entering the epicenter of world biodiversity.

At nightfall, we camped on a small beach on the riverbank. I was traveling with a Peruvian anthropologist, an American environmental foundation director, and two Swiss friends. We were on our way to inspect a project run by a local Matsigenka community. My companions retired early after a long day on the river, but I sat up next to the fire listening to the hypnotic wall of sound produced by the forest. I could hear cicadas and crickets buzzing, birds singing odd melodies, frogs croaking, and monkeys howling. In the Amazon, nature plays loud, especially at night.

The next morning we continued downriver and reached the docking site of a lodge called the Matsigenka Centre for Tropical Studies. It was perched on a high bluff overlooking the river. I was curious to see this community-development project, which claims to combine income generation with respect for biodiversity. We climbed a long wooden staircase and walked into the lodgeâ ™s entrance to find polished hardwood floors and fully screened corridors. Further inspection revealed clean beds and tiled bathrooms with hot water. In all my years of visiting rural settings in the Peruvian Amazon, I had yet to see this level of comfort. As a Matsigenka receptionist took down our names, an American client walked past and asked casually: â œHad a good trip?â

I settled in and took a shower, then joined my companions in the dining area. We ordered papaya juice, fish, and rice from a Matsigenka waiter. Several other tables were occupied by a group of Americans, who spoke excitedly about the birds they had observed that morning in the forest. After lunch, one of the men came over to our table and introduced himself as Charlie Munn. A tall man with a large forehead, Munn began telling us about his profession and passion, studying birds. He had been coming to the Peruvian Amazon for twenty-five years, he said, and had done his doctoral research in the nearby Manu Biosphere Reserve. Working with Matsigenka Indians, Munn and his team discovered that macaws, the colorful giants of the parrot world, gather daily for most of the year at large banks of clay, which they peck at and consume in small morsels. When Munn and his colleagues first observed this behavior in the Manu, they assumed they had found the only macaw â œclay lickâ in the world. But with the help of indigenous guides, they went on to find dozens more, one of which was an hourâ ™s walk from the lodge we were sitting in.

All this was new to me, and I had not expected to run into a leading bird scientist while traveling down the Urubamba. Nor was I used to people presenting their work so forthrightly. But I found Munn interesting and did not interrupt him. He said he and his research team were initially mystified by the macawsâ ™ consumption of clay. They assumed the clay contained salts and minerals that supplement the birdsâ ™ primarily vegetarian diet. Then a graduate student analyzed the seeds commonly eaten by the macaws and discovered they contain toxic alkaloids. Macaws prefer eating the seeds of fruit to their pulp, and they use their powerful, hooked beaks to crack and consume seeds from many different trees, unlike most birds in the tropical forest. It turns out, Munn said, that the clay the birds eat binds to these toxins and speeds their elimination from the body, and probably also lines the gut and protects it from the chemical erosion by the seedsâ ™ toxins. Macaws take almost daily doses of clay to detoxify themselves, which allows them to eat foods that other animals cannot tolerate. He added that macaws choose clays with a much higher capacity to bind toxins than adjacent bands of clay, which they shun. They prefer clays rich in kaolin, which humans use to cure food poisoning.

As I listened to Munn, I realized that this was an example of intelligent behavior in nature. Homing in on the right clay and consuming it allows the birds to eat seeds and unripe fruits that are unpalatable and even lethal to other species. This gives them an edge over most other animals in their environment. But, I wondered, is this the kind of intelligence that humans exert when swallowing kaolin? Or is it just â œinstinct,â or an â œevolutionarily adaptive behaviorâ ? Are the birds being choosy and cunning by some kind of automatic process? Or do they know what they are doing, like thinking subjects? Are humans â œsmartâ when they eat clay, while macaws are merely â œinstinctiveâ when they do the same?

Before I could ask Munn these questions, my companions and I were invited on a tour of the lodgeâ ™s wildlife circuit. I thanked Munn for the interesting information and made a mental note to speak with him later.

Outside, a Matsigenka guide was waiting for us. His name was Hector Toyeri Andres. He was twenty-one years old, with jet-black hair and dark eyes He wore pants and a T-shirt, but walked barefoot with a traditional cotton bag hanging from his shoulder.

We greeted each other and he started talking in a strange language, which I soon realized was English. He said he would show us the animals. This was the first time I had heard an Amazonian Indian speak English. We headed off into the forest. Despite the midday heat, the air under the trees was fresh. Toyeri motioned for us to walk quietly single file behind him. After a short while he stopped and pointed to a tree ahead of us, and whispered something in English, which I did not understand. He delved into his shoulder bag, pulled out a largish book called *Birds of Colombia,* and flipped through it until he found a page filled with bird names like â œwhite-winged shrike-tanager.â Toyeriâ ™s pronunciation was not so badâ ”I was just not familiar with the names of many tropical birds.

This was also the first time I had seen an indigenous Amazonian treat a book as a transportable tool for understanding the world. Traditionally, indigenous Amazonians have oral cultures, and do not use texts. Toyeri was from a new generation and had received training as a guide for ecotourists. He moved like a hunter, gliding swiftly and silently across the forest floor. He seemed attentive to movements at all levels. We walked across several streams and saw different birds and insects including leaf-cutter ants busily at work. But mammals were few and far between. At one point Toyeri spotted a large gray anteater climbing a tree, seemingly untroubled by our presence.

After the wildlife circuit, I spent the afternoon writing notes, then took a nap and fell into a deep sleep. When I awoke, night had fallen. I wandered into the lodgeâ ™s dining area feeling a bit groggy, and found the American bird-watchers gathered around a portable computer. They were voicing enthusiasm at images of macaws they had filmed that morning. I took a look and saw explosions of colorâ ”green, red, blue, yellow, close-ups of macaws vying for space on a clay cliff and squawking loudly. As I watched these bird-watchers marveling at what they had witnessed here at the Matsigenka Centre for Tropical Studies, I was reminded of a dream described by ethnobotanist Glenn Shepard, who spent years working with Matsigenka shamans in the Lower Urubamba Valley, studying their knowledge about plants. Inspired by a tobacco paste prepared by a shaman, Shepard dreamed of â œa team of Yankee doctorsâ working alongside English-speaking Matsigenka botanists in elaborate research facilities. Though only three years had elapsed since Shepard wrote about his dream, it seemed to be coming true.

At dinner, my companions ordered a bottle of Peruvian wineâ ”to â œcontribute to the local economyâ â ”and we started storytelling and philosophizing. I was hoping to catch Munn to ask him about macaw intelligence. But the bird-watchers, including Munn, retired early, because they planned to get up at 4 A.M. and hike to the clay lick to observe the macaws and other parrots again. Though my companions and I had resolved to accompany them, we stayed up far too late, talking.

After a short nightâ ™s sleep, I put on my shoes by candlelight. It was 4:15 A.M. and we were running late. The bird-watchers had already left the lodge. Toyeri, our Matsigenka guide, was waiting for us outside. He told us we had to hurry to be there before the birds arrived. We headed off equipped with flashlights, following Toyeri into the forest. He led us on an energetic, uphill hike that took an hour. I used my flashlight to beam a path through cold, vegetal darkness.

By the time we reached the clay lick, day was almost breaking. Toyeri took us to the base of a fifty-yard cliff made of reddish clay and ushered us into a sizable blind made of palm leaves. The bird-watchers were all there and had deployed their cameras and powerful binoculars on tripods. The blind had the feel of a nest of spies. We were told to be quiet, because the macaws and other parrots were due to appear any time, and visible or audible human presence would keep them away.

One of my travel companions was an electronic musician who wished to tape the sound of the birds. He realized that conditions in the blind were not optimal for recording. He needed complete silence in the vicinity of the microphone. He discussed the problem with Toyeri, who made a gesture for us to follow him. Toyeri took us to a small mound one hundred yards opposite the clay cliff. We hid under tree cover in a spot that allowed us to peek out through the vegetation and catch a panoramic view.

The clay cliff in front of us began to echo with bird calls, chirps, and squawks. It sounded like an aviary. Out of nowhere, hundreds of birds had congregated. I closed my eyes and listened. The sound reminded me of the scene in Hitchcockâ ™s film *The Birds,* in which thousands of seagulls flock together and let off a threatening din. But these macaws sounded raucous and celebratory, rather than threatening.

During a pause in the sound recording, I asked Toyeri to name some of the birds we were hearing. He pulled out the *Birds of Colombia* book from his shoulder bag and started reeling off names in English, which I noted down: scarlet macaws, blue-and-gold macaws, chestnut-fronted macaws, white-eyed parakeets, yellow-and-crowned parrots, blue-headed parrotsâ ¦

The cliff had become a wall of spinning rainbow colors. The racket the birds made was both symphonic and deafening. As they hung out on the red-clay cliff, they also appeared to squabble, tumble off, and dive-bomb one another, twirling and pirouetting, while other birds flew over to nearby trees letting out loud screeches. Magnificent colors and movements blended with dissonant sounds in a dazzling spectacle.

I asked Toyeri what he thought the birds were saying to one another. He replied (in Spanish): â œThey are all friends. They make such noise when they eat clay because they are saying â ˜everybody come over here, itâ ™s really good here.â ™ For them, the minerals and salts are like sweets for us. It is their food. They do this from half past five to seven-fifteen. Then they all go their separate ways to the forest. This is like their breakfast.â

It was difficult to know what the macaws had in mind as they feasted on clay. But they were obviously enjoying a very social breakfast before a day of solitary foraging in the forest canopy. I asked my musician friend what he made of it. â œThis reminds me of a party,â he said, â œor an after-hours, Iâ ™m not sure which. It might even be the rave itself!â

As we sat on the forest floor waiting for the end of the birdsâ ™ riotous clay fest, I pondered the difficulties of gauging intelligence in nature. Here were birds behaving in ways strongly reminiscent of humans, holding loud get-togethers and food fests, and self-medicating by using the most detoxifying clays. They did not behave like machines or automata, but like intelligent beings. Yet the intelligence that seemed to lurk inside them remained elusive and hard to defineâ ”seen and heard, but not grasped.

Suddenly, a hummingbird with a long pointed beak zoomed in on us. The intense beating of its wings sounded like a whirring motor. It remained suspended in midair for long seconds, only a few feet from our faces, appearing to observe us and to size us up. Then it went on its way, searching from flower to flower for nectar.

The parrotsâ ™ get-together came to an end as abruptly as it began. The birds started flying off in different directions over the forest. Within minutes, the party was over, and a crowd of about a thousand had dwindled to a handful of individuals. My watch indicated seven-fifteen. These birds were punctual.

We made our way back to the lodge. Soon we would be getting back into the canoe to continue our voyage downriver. I readied my backpack, then sought out Charlie Munn.

We met in the lobby and had a short exchange. I told him I was starting to research a book on intelligence in nature and asked if he thought macaws act intelligently at clay licks. I expected a quizzical gaze in return, but he looked straight at me and said: â œThese are smart birds.â He went on to suggest that I read an article he published in the journal *Nature* called â œBirds That â ˜Cry Wolf.â ™â He said he had observed birds in the nearby Manu Biosphere Reserve that act as sentinels and give alarm calls when they sight predators, but that sometimes use their power to deceive other birds. These deceptive sentinels occasionally feed themselves by giving out false alarm calls that cause other birds to panic and abandon the insects they have just flushed out of trees. Munn said that deception usually requires intelligence.

I asked whether he thought these birds acted intentionally. He nodded. â œThere are even birds in the Manu who can tell the difference between Matsigenkas who work with scientists and those who are hunters. That piece of data is unpublished, and you can put it in your book if you like.â

Later that day, my travel companions and I continued downriver in the motorized canoe. The sun glared down on us, hot and heavy. I stared into the water gliding by. My mind began to wander, and I thought about birds.

Western observers have long minimized the mental capacities of birdsâ ”hence the term *birdbrain,* meaning â œstupid person.â Birds do have small brains relative to humans, but why should small brain size rule out the possibility that birds might think and make decisions?

Members of the crow familyâ ”including ravens, magpies, jackdaws, and jaysâ ”generally receive the highest notes for intelligence from scientists. For example, one crow, the Clarkâ ™s nutcracker, can remember up to thirty thousand hiding places for the pine seeds it gathers and buries for safekeeping. And in one recent laboratory experiment, scrub jays who cached food while observed by other birds were found to modify their hiding places when the observing birds were no longer presentâ ”indicating both social memory and foresight. But crows are not the only smart birds. Even pigeons appear to be brighter than many people suspect. One recent experiment demonstrated that pigeons can tell the difference between paintings by Van Gogh and Chagall. The birds received training in which they were rewarded for pecking at paintings by Van Gogh but discouraged from choosing Chagalls. Then they were shown previously unseen works by both painters. The pigeons as a whole performed almost as well as a parallel group of university students majoring in psychology.

Many consider learning to be a hallmark of intelligence. It turns out that almost all of the known nine thousand species of birds have a song, but about half of them have to learn how to sing. If they lack the opportunity to learn, they develop songs different from those heard in nature. Young birds must listen to adults, then practice on their own. Birds even appear to practice singing in their dreams. Research shows that sleeping songbirds fire their neurons in intricate patterns similar to those they produce when singing. Some songbirds, like canaries, change repertoires every year. Scientists correlated this to changes in the birdsâ ™ brains and went on to find that adult canaries generate a steady stream of new neurons. This overturned a century of scientific theory which held that brains in adult animals do not change. Now it appears that all animals including humans grow new neurons throughout their adult lives. On this count, our brains are not so different from those of birdsâ ”fortunately.

Indigenous people in the Amazon and elsewhere have long said that birds and other animals can communicate with humans. Shamanism is all about attempting to dialogue with nature. When shamans enter into trance and communicate in their minds with the plant and animal world, they are said to speak *the language of the birds.* Historians of religion have documented this phenomenon around the world.

Scientists and shamans could join forces to try to understand the minds of birds and other animals, I told myself, gazing into the waters of the Urubamba.

Our canoe approached a break in the forest cover on the right bank of the river. This was where an international consortium led by an Argentinian petroleum company was building a center of operations called Las Malvinas (the Falklands). Pristine forest gave way to bulldozers and earthmovers. There were huge mounds of orange clay, deep pits filled with water, makeshift housing for construction workers, giant tubing lying in stacks, and a landing pad for helicopters. Beneath the Urubamba Valley lies one of the worldâ ™s largest known deposits of natural gas. Matsigenka communities own the lands, but the Peruvian state owns the subsoil and has granted the right to exploit it to the petroleum consortium.

Traditionally, shamans around the world report dialoging with nature about the extent to which humans may exploit it. In particular, shamans in numerous indigenous societies refer to an entity known as the â œowner of animalsâ with whom shamans negotiate in their trances for the release of game. The owner of animals is said to protect plants and animals, and place limits on the productive activities of humans when they act recklessly or greedily.

What, I wondered, would the owner of animals say about driving a pipeline into the heart of world biodiversity? Perhaps that we are birdbrains.

Chapter 2

AGNOSTIC VISIONS

Prior to traveling in the Urubamba Valley, I had visited an Ashaninca shaman named Juan Flores Salazar, who lives in the Pachitea Valley, in the middle of the Peruvian Amazon.

The hike from the Pachitea River up to Floresâ ™s place in the hills took me through primary rain forest. The air smelled musty and fertile, like in a greenhouse. In the thick vegetal tapestry all around me, every plant seemed different from every other. Even the trees that towered up into the sky all seemed different from one another. And those that had partially fallen over and begun to decompose, had arrays of plants growing out of their rotting trunks. Rain forests stand on poor soils, but they embody exuberant life.

Two years before, I had asked Flores to administer ayahuasca, a hallucinogenic brew, to three molecular biologists who had come to the Peruvian Amazon to see if they could obtain scientific information in such conditions. Flores had risen to the occasion. The night-time ayahuasca sessions he conducted gave the scientists information about their research; and during the daytime Flores spent hours answering the scientistsâ ™ questions. The three scientists came away from the experience saying it had transformed their way of looking at nature. Under Floresâ ™s guidance, two of them reported communicating in their visions with â œ-plant mothersâ from whom they received information about their research. Throughout the encounter Flores did not talk much unless spoken to, but he exuded confidence. The day after an ayahuasca session that the scientists had found remarkable, I asked him how he felt. He pointed his index finger straight ahead and said: â œLike a bullet.â

His words came back to haunt me when I learned several months later that Flores had stepped through the trip wire of a hunterâ ™s trap while gathering plants in the forest near his home and had received a blast of shotgun pellets which shattered his tibia. His friends barely managed to carry him out in a hammock and get him to a hospital on time. On arrival he had lost so much blood the doctors said he had only a few hours to live. They saved his life with a transfusion, then they saved his leg by replacing the shattered bone with steel plates. Flores spent a week in the hospital, then insisted on returning home. His friends transported him back to his forest retreat. For a month he took antibiotics as prescribed by the doctors, then set about healing himself with plants. In the meantime, the police identified the man who set the trap in the forest, an impoverished colonist living in a nearby frontier town. Flores could have pressed charges and had him sent to prison. Instead, he simply asked for an apology and encouraged the man not to set up further traps.

It took an hour to reach the house Flores had built next to a stream of near-boiling water that flows from a geothermal source in the forest. I arrived in the late afternoon and found Flores standing in his garden. His high cheekbones and slanted eyes made him recognizable as an Amazonian Indian.

Flores had already told me a bit about his life. His grandparents were enslaved during the rubber boom in the early twentieth century and taken from the Pachitea Valley to work downriver. Flores was born in 1951 in a community of displaced Ashaninca people who were only then shaking off the shackles of forced labor. As a child, he attended primary school and learned to read, write, and speak Spanish. His father, a reputed shaman, died when he was ten. This prompted Flores to follow in his fatherâ ™s footsteps. He devoted his youth to apprenticing himself to several Ashaninca *maestros*. He traveled all around traditional Ashaninca territory, then settled near the town of Pucallpa, where people gradually recognized his skills as a plant specialist and healer. He only recently returned to the Pachitea, the homeland of his grandparents, to set up a healing center in the forest.

Flores has spent most of his life going between worldsâ ”forest and city, indigenous and mestizo, traditional and modern. He is both an indigenous person and a cultural hybrid. When he walks barefoot through the forest wearing a crown of feathers and a traditional Ashaninca cotton robe, he looks like an indigenous shaman. And when he wears a shirt, jeans, and boots, he moves with ease in the world of mestizos.

The day after my arrival, I interviewed Flores on the thatched-roofed platform by the river where he conducts healing sessions. He sat at a homemade desk wearing a colorful cotton headband with Ashaninca designs and a white shirt that made him look like a doctor.

I wanted to record his view on intelligence in plants and animals. I began by asking what he thought the difference was between humans and other species.

â œ*Bueno,â* he said. â œI can say the difference is that human beings have voices with which to speak, whereas animals have their knowledge but do not have the property of speaking, or the strength to speak in a way that humans can understand. The same is true for plants. So there is the difference: We cannot speak with them. But through the knowledge of healing, and through the spirits of plants, we can speak with animals and we can also speak with plants.â

I asked him to explain how one could do this. He said that shamans use plant mixtures such as ayahuasca to dialogue with the spirits of natureâ ™s beings. In their visions, shamans communicate with these spirits by singing *icaros,* or shaman songs. Plants receive these songs â œfrom inside, from the heart,â he said, and shamans thank plants for the knowledge and healing they impart by singing these songs.

I asked Flores what he thought about intelligence in plants and animals. He said that animals make plans as they go about their lives in the forest and decide where to walk during the day and where to spend the night. And he said that plant spirits wander from one place to another to heal people, â œbecause plants care a lot about humanity.â

Several of his ideas contradicted the Western, academic worldview, but he was stating clearly what many Amazonian people consider to be true. Who was I to rule out the possibility of communication between humans and other species? Perhaps shamans know things about nature that science has yet to discover. Instead of contradicting Flores, I wanted to grasp his point of view. I asked if he still spoke with the owner of animals.

â œIn this case, yes, I have been practicing this for a very long time, in regards to everything I do. Because all things have to be done from the heart, and this is true concerning taking an animal, or a plant,â he said. â œThe last time I spoke with the owner of animals was a week ago. For example, to come and settle here, I had to ask the owner of animals.â

â œCan you tell me what he or she looks like?â

â œHe appeared in the form of a jaguar sitting at my side, and he was looking at me. I was also looking at him. He transformed himself into a person. Then he told me, â ˜You may pass. You may come here.â ™â

Later that day, we went for a walk in the forest. Flores hobbled along the path slowly. His accident had left him with a permanent limp. We reached a spot above a small waterfall and sat on boulders next to the stream surrounded by trees. We talked for a while about his wounded leg. For someone who had risked death, he showed impressive fortitude. I asked if he considered death to be a problem.

â œIt is not a problem,â he said, laughing.

â œAre you not afraid of death?â

â œI am not afraid of death because death comes to me and I am good friends with it. It will decide when to take me.â

â œHow did you become friends with it?â

â œI became friends with death through all the sufferings I had to endure to become a shaman. In shamanism one has to know death. More than anything else, death is very close to the shaman, to the *curandero.* So that is why we know death more closely. It accompanies us.â

He said healers risk being attacked by â œsorcerersâ â ”or shamans intent on causing harmâ ”but he knew which plants to use to protect himself. â œNow I am sincere when I tell you I fear nothing, absolutely nothing. I am well centered in what I am doing with traditional medicine and in relation to anything that could come against me. I want to say that for me, living or dying is one and the same. I am not worried that someone might kill me. If they want to kill me, they can do it, but I do not believe they will. And there has to come a time, which will be signaled, when death comes to me, and I will die. So I am sincere when I say I am afraid of nothing.â

His fearlessness inspired me to ask him if he had any advice regarding how to talk about intelligence in nature.

â œSay what you think,â he said. â œNothing more.â

That evening Flores conducted an ayahuasca session on the thatched-roof platform by the stream. He was assisted by several apprentices, men and women who worked with him so that they could learn from him. He began by administering the ayahuasca in a shot glass. It was thick and unusually sweet compared to other brews I had tasted. Then he blew out the kerosene lamp and we sat in the dark for a while. I found myself hearing melodies in the sound of the nearby stream, then realized that Flores was whistling very quietly, at a barely audible level. He went on to sing simple melodies in loops, with a razor-blade-and-honey voice. He sang in Ashaninca, Quechua, and Spanish. He also chanted syllables over and over again, without words: *â œNye-nye-nye na-nye-nye-nye.â* Between songs, he blew tobacco smoke on the participants and took swigs of perfumed water which he sprayed in the air around us. As a plant specialist who works with fragrances, he is an *ayahuasquero* and a *parfumero.* His apprentices also took turns singing, blowing tobacco smoke, and spraying perfumed water.

The combination of the hallucinogenic plant brew and the waves of sound, smell, and smoke orchestrated by Flores unleashed a flood of thoughts and images in my mind. In the realm of visions I saw a long, tall figure like a cross between Picassoâ ™s Don Quixote and the Egyptian god Horus stalking around a carnival scene. I knew I was hallucinating. Floresâ ™s singing resonated in my bones like old music reaching back to the roots of our species. I eventually remembered to focus on intelligence in nature. I saw myself as a biological organism, my heart pumping blood without my thinking about it, lungs breathing when I sleep, neurons firing when I think, body repairing itself when wounded. I felt like a wet robot becoming self-aware, careening toward a dreadful question: Who programmed me? What if an intelligence acted not only in the intricate workings of present-day cells, but also as a creative force at the origin of life forms?

The question was dreadful because I am an agnosticâ ”meaning I know that I donâ ™t know, in particular regarding final causes. The word comes from the Greek *a gnÃ´stos,* not known. Floresâ ™s ayahuasca session led me to ponder my presuppositions. A scene from my adolescence came to mind: I was sitting in a religion class in a Swiss high school listening to the teacher, a Benedictine monk in white robes, who had a round, bald head; he was talking with enthusiasm about â œGod of the universe.â At one point, his shiny head caught my attention and prompted me to ask a question: â œAs our heads are no bigger than soccer balls, and as the universe is so immense, how can we know with certitude about God of the universe?â To my surprise, the monk told me to leave the room because of the â œimpertinenceâ of my question. As I stood in the lonely corridor outside the classroom door, I became certain the question had validity. Surely the size of our brains limits our capacity to grasp things. So how does a reliable understanding of the universe hold in three pounds of gray, fleshy matter? From that moment on, I found it difficult to subscribe wholeheartedly to concepts I canâ ™t understand, such as â œGod of the universe.â

I sat through Floresâ ™ ayahuasca session on a mattress, scribbling in my notebook in the dark. Ayahuasca visions can contain information and insights, and writing them down helps me to remember them.

I knew that the concept of a creative force at the origin of life is a matter of faith. Some Christian scientists and philosophers contend that the biological world is rife with evidence of â œintelligent design.â They say that cells contain protein machinery that is too complex and precisely engineered to have evolved through a series of random mutations. And they say that the DNA in our cells contains huge amounts of complex information that cannot have originated in chance and necessity. They argue that this â œirreducible complexityâ points with near certainty to the existence of an â œintelligent designer,â often a thinly disguised version of God. By associating â œintelligenceâ and â œdesignâ when discussing nature, proponents of this view move away from the verifiable to the theological. The existence of God, or a designer, is a matter of belief and cannot be demonstrated, no matter how much evidence one piles up regarding cellular complexity.

I wanted no truck with the intelligent-design movement. By considering intelligence in nature, I was not seeking to explore untestable theological questions about how the complexity of cells may have arisen. Rather I wanted to understand the ongoing decision making in nature and the intelligence that seems to manifest itself in the workings of all living organisms including myself. I was interested in the intelligence of cells and organisms, rather than in events that may have occurred billions of years ago involving, for example, a â œGod of the universe.â

And replacing God with â œblind chanceâ did not solve the problem. Atheism is theism denied, or the other side of the same coin. The word comes from the Greek *a theos,* without god. Believing that chance and necessity suffice to explain all of nature is a form of faith that has not been conclusively demonstrated. Evolution is ongoing, but believing that chance drives it is an act of faith.

The ayahuasca session was winding down. Flores had ceased to sing, letting us bathe in the sound of the rushing stream and the forest at night. My mind was flooded with thoughts. I pondered the importance of chance. Nature does seem to use chance as a source of variety to diversify and improve itself. My own physical characteristics come from the shuffling of genes that occurred in the reproductive cells of my parents. The genetic deck of cards is shuffled and reshuffled between generations in a highly coordinated process called meiosis, which appears to use randomness to fuel diversity. Chance may have enriched me, but I doubted that it caused me. That life on earth arose by chance is as difficult to prove as the belief that God, or some other entity, created it. Some questions are intriguing to people because they concern us, but that does not mean that they can be answered in any definitive way.

Once I had finished taking notes, I sat quietly in the dark.

Chapter 3

TRANSFORMERS

After visiting Flores, I traveled to Pucallpa, the second-largest town in the Peruvian Amazon. The Pucallpa region used to be part of the homeland of the Shipibo people, but it was overrun and deforested by outsiders during the twentieth century. Despite this loss and devastation, the Shipibo have maintained a strong sense of identity. They recently gained communal land titles to large parts of their territory, and they continue to produce beautiful handicrafts for which they are famous. They are also reputed for the power of their shamans.

I paid a visit to a Shipibo shaman named Guillermo ArÃ©valo Valera. Author of the book *Medicinal Plants and Their Benefits to Health,* which the federation of indigenous people of the Peruvian Amazon published in 1994, Guillermo is recognized by his peers. People now come from foreign countries to consult him. He lives in a mainly Shipibo neighborhood on the outskirts of Pucallpa. The day of my visit, I knocked on the door and found several of his children sitting in the living room watching television and stroking a large boa constrictor they had just captured. Guillermo was not home yet. The children invited me in to wait. As snakes make me uneasy, I chose to sit across the room at the dining table, rather than with the children on the sofa. Unlike some houses in the neighborhood, which were shacks with electricity, Guillermoâ ™s house has a concrete floor, plumbing, and a well-equipped kitchen.

I spent several hours catching up on my notes, and keeping an eye on the serpent. It was a rather beautiful and calm animal of gray color with black markings and an orange-tipped tail. At one point, the children went outside, and the boa slithered out of sight under the sofa.

Guillermo arrived in the late afternoon. A small, strong man with a commanding presence, he greeted me warmly and invited me to follow him up to his office in the top part of the house. During our conversation, I asked whether he still communicates in his visions with the â œowner of animals.â

â œBueno,â he replied. â œYes, that is possible. I did it several times in the days when I did not come to the city. But now it is no longer possible to have this contact for the very reason that nature is already quite contaminated and destroyed. So the spirits of animals are obliged to stop existing in this place. Now the spirits of animals, of the forest, of the earth, go to other unknown places. We do not know where they go, but they disappear from the place, as if abandoning it, and it is no longer inhabited by spirits.â

That evening I participated in the ayahuasca session led by Guillermo and his eighty-year-old mother, Maria, in a hut in their backyard. The participants were mainly local people seeking guidance or relief from physical ailments. The mother-and-son shaman team sang melodies that were intricate and interwoven, like the labyrinthine designs of Shipibo artwork. Their voices quavered as they chanted cascades of high-pitched notes in their language. It was like music for charming serpents, hair-raising and hypnotic. And it combined with the neighborhoodâ ™s background noiseâ ”an open-air discotheque, motorbikes passing, insects buzzingâ ”to form a mind-bending envelope of sound. They were keeping traditions alive in a world of change by singing songs of healing in their backyard.

Shipibo shamanism is changing fast, according to Rama Leclerc, a French anthropologist who has studied the acquisition of knowledge among the Shipibo of the Pucallpa area. She told me: â œSome young shamans in urbanized communities incorporate Christian prayers into their sessions. And they also consider the spirits of animals and plants from which traditional shamans get their power as subforces created by a superior entity, God. Consequently, â ˜modern shamans,â ™ as they call themselves, must establish direct contact with the main source of power. In reaction to this, some old shamans say that the younger generation fails to respect the strict rules of apprenticeship, and lacks knowledge about the natural world.â

Shamanism is transforming itself.

From Pucallpa, I caught a plane to Iquitos, the largest town in the Peruvian Amazon. From there I made my way to Zungarococha, Lake Catfish, to visit a teachersâ ™ training program at a bilingual, intercultural school, where young people from fifteen indigenous societies learn to teach their own language and culture, as well as Spanish and science. I had an appointment with three â œindigenous specialistsâ â ”men with extensive knowledge about their own language and culture, and who teach at the training program. As these indigenous specialists work hand in hand with Peruvian professionals, such as mathematicians, linguists, and agronomists, they are used to relating indigenous knowledge to science. We met on the verandah of their living quarters, a small wooden house with mosquito screens overlooking the lake. They knew I wanted to interview them about intelligence in nature.

The first specialist, Nahwiri Rafael Chanchari, represented the Shawi people. He had a foxlike face and thick black hair cropped in a bowl. Like his colleagues, he dressed simply, wearing a short-sleeved shirt, pants, and sandals. I started by asking him why he thought scientists had difficulty seeing the spirit side of the natural world. â œLook,â he replied, â œI believe that science is materialistic. Science wants to see concrete evidence when it tries to answer the questions it asks itself. In the indigenous world, we also believe in the material. Trees exist, as matter, as wood, as firewood. But this material existence is not all there is to it. Deep down, they are also beings. And science recognizes this when it calls insects and trees living beings. We Shawi think that all living beings have souls, which are their own spirits. If they did not, they would not have a reason to live. Take a stone, for example. For science, a stone is inorganic matter, that is what I think they call it, matter which has no life. And it considers earth and water in the same way, as lacking life. But for the Shawi, a stone has its own soul, as does water. And earth also has its mother. For us, everything is alive.â

â œDoes each little stone have a soul?â I asked.

â œIt depends on the size. A simple little stone does not. But a stone which is ten square meters, or huge rocks which are fifteen square meters, have mothers. Tiny little grains of sand do not. But when you go to the beach, you find that all the sand taken together, as a beach, has a mother, or a soul.â

He spoke Spanish fluently and appeared to have thought about these questions before. I asked if he could explain the difference between the â œspiritâ of an individual plant and its â œmother.â He remained silent for an instant, then replied: â œRight. A tree has a soul like a human being does. The Christian world considers that humans have souls. It is the same with a tree. It is material and it also has a soul or a spirit which may present itself to you in your dreams in the form of a person. And taken together, trees have their mother, meaning to say mother of the forest, and mother of the species. This is what we call *tana-ashi,* mother of an ecosystem so to speak. For example, in a place where there are a lot of *irapay* palms, that is where the mother of *irapay* lies. It is like a general soul. That is the difference between the mother and the soul of each tree.â

The second specialist, Akushti Butuna Karijuna, represented the Kichwa people. He had a round face, short hair, and piercing dark eyes. I asked him to compare Western science and indigenous knowledge. *â œBueno,â* he said. â œWe speak on the basis of our visions, whereas scientists do not believe in visions. Instead they go and study. That is why it is a little different.â

I asked whether he saw a difference between knowledge acquired from vision and knowledge acquired from study. â œI see some *gringos* saying things somewhat similar to what we see in our visions,â he replied. â œIt is on the same level. But for example, regarding the creation of humans, I do not know, *gringos* have another knowledge which they were brought up on. Our knowledge is different. We get it from the animals, for example from the birds. The bird of the Kichwa people is the yellow-fronted parrot. It is from this bird that we originated and multiplied.â

Amazonian people commonly believe that plants and animals are related to humans, and that nature metamorphoses and undergoes constant transformation.

I asked the third specialist, Usi Kamarambi, why, in his opinion, *gringos* have difficulty understanding that plants contain spirits. He had a joyful, ageless face. â œBecause they just do not know,â he replied. â œThatâ ™s why. We Kandoshi people believe that plants, trees, all have spirit.â

I asked if he thought the *gringosâ ™* problem is lack of knowledge. â œLack of knowledge to understand nature,â he said, agreeing. â œLack of know-how about how to see visions, what to drink, how to do it.â

He spoke basic Spanish with a thick, throaty accent. He went on to say that Kandoshi people use ayahuasca, datura (*toÃ©*) and tobacco to attain visions that allow them to understand nature. He said he had used these plants himself and had spoken with the â œmothersâ of plants, in particular with the â œowner of daturaâ (*el dueÃ±o de toÃ©*). I asked whether he had also spoken with the â œowner of animals,â the entity said to represent the â œownersâ of all species.

â œI did not speak with the owner of animals, no. I could only see her. I could see where all the animals exist, many kinds of different animals. And there was their owner, the mother of animals.â He used the concepts of â œownerâ and â œmotherâ interchangeably.

â œWhat did she look like?â I asked.

â œHer body was covered in feathers, feathers of animals, birds, and her feet were like a personâ ™s, and so were her fingers, but she had very long nails.â

He described the owner of animals as a hybrid being, as do many indigenous people around the world.

A large green parrot screeched and squawked from a nearby palm tree, interrupting the conversation. Once it had quieted down, I steered the conversation toward the subject of intelligence in nature. I asked the specialists if they thought animals think.

Akushti Butuna Karijuna, the Kichwa specialist, said, â œWe see animals, they have thought. Ants, for example, prepare their supplies, stock their food, go fetch it, and bring it back to the right place.â

â œAre they thinking about the future?â I asked.

â œThinking about the future,â he agreed. â œThatâ ™s why we, in our knowledge, see that animals also think. They know how they are going to save themselves, how they are going to prepare their nests.â

Usi Kamarambi, the Kandoshi specialist, said, â œAnimals, for example insects, also have their ideas, their thoughts. It is just that we cannot hear that they have their own voices. They understand one another, they hear one another. Insects talk to each other. For example, leaf-cutter ants, when they go to get leaves in such-and-such a place, they all go there together, then they carry the leaves back to their nest. It is like a communal work party. They also have their experience, how to know for example.â

Nawhiri Rafael Chanchari, the Shawi specialist, said, â œWe believe that animals think. Monkeys, birds, animals, when they see you, they smell you, and they tend to run away from you. So we think that in their own world, they also think and converse. When we see peccaries [wild pigs], we see animals. But in their world, they are not animals, they too are human beings, and they can speak to one another. They make plans regarding where they are going to go. They check to see if their group is all together, or if one is missing, what happened. Each place where they sleep, they keep lists, they control things as they go. And that is the experience that we have through our elders. In other words, animals have their own world. They are also human beings in their world. We see what appears to us as an animal, but in their own world they think and reason and only then start out looking for their food.â

He said that animals and plants contain spirits which humans can see when drinking ayahuasca. He said these spirits are beings that appear to us in human form when they want us to see them and learn something. â œThey can transform themselves. Even though a human being can also transform himself, according to his capacity to sing *icaro* [shaman] songs. For example, a man can transform himself into a jaguar.â

â œWhat does one have to do for that?â I asked.

â œFor example, know a lot of *icaro* songs. There is a discourse which is very dangerous to learn, even though it is of the *icaro* song. You learn it and become a jaguar, but as a person. It cannot be taught. That is a difference: Human beings, depending on their capacity to discourse, can transform themselves into jaguars. Whereas, a jaguar cannot transform itself into a human.â

I asked the Kandoshi specialist how shamans turn into jaguars. He replied, â œThe shaman transforms his soul into a jaguar, but not his body. And this jaguar can go and cause harm to others, because the shaman is directing it, because his soul is inside the jaguar body. But this jaguar is an animal. So the shamanâ ™s soul transforms itself and enters into the jaguar. Thatâ ™s where the shamanâ ™s soul is. Inside the jaguar.â

At the end of our meeting, the specialists showed me a book about Amazonian cosmovisions that they and their colleagues had just published. It contained hundreds of illustrations concerning the indigenous Amazonian view of the world. As I skimmed through it, I noticed a number of images depicting hybrid beings, half human and half animal.

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THAT NIGHT I sat on the bed in my hotel room in Iquitos under the glare of a bare lightbulb and thought about what the three specialists had told me. I had the feeling they had relayed important information that I was failing to understand. I felt both excited and puzzled. I knew that animal transformation is a common theme among Amazonian shamans. Anthropologist Gerardo Reichel-Dolmatoff reported extensively on the subject while devoting his career to studying the indigenous people of Colombia. â œAll shamans are transformers,â he wrote, â œand are said to be able to turn at will into jaguars, huge serpents, harpy eagles or other fearful creatures.â According to Reichel-Dolmatoff, shamans use plant hallucinogens to get into the mind-set of another species: â œProstrate in his hammock he will growl and pant, strike the air with clawlike fingers, and those present will be convinced that his wandering soul has turned into a bloodthirsty feline. However, shamans do not claim to acquire an animal essence but merely to â ˜behave like animalsâ ™; they acquire certain faculties for which these animals are known: birdlike flight, aggressiveness, nocturnal vision, agility.â

Humans with animal features, bird-headed humans in particular, show up prominently in some of the most ancient prehistoric images. Lascaux, the French cave known as the â œSistine Chapel of prehistory,â is marked by the image of a bird-headed man, in a scene that includes a bison and a bird on a stick. This image was painted about 17,000 years ago.

Les Trois FrÃ¨res, another French cave containing several hundred prehistoric paintings and engravings of animals, also features several half-human figures, the most prominent of which is a stag with human arms and legs. Known as the â œSorcerer,â it looms above the superimposed engravings of a multitude of animals. It was painted approximately 13,000 years ago.

In Chauvet, the recently discovered French cave that contains the oldest-known paintings in the world (estimated to be about 31,000 years old), there is an image of a composite being, part woman, part bison, part feline.

It is hard to know what the prehistoric people who produced these images really had in mind. They died too long ago and left no texts explaining their motives. However, scholars have been tempted to interpret these images, because they go so deep into the ancestry of our species. Some view the chimera figures as â œarch-sorcerers,â or as shamans partially transformed into animals, or as representations of the owner of animals. But others have pointed out that shamans do not need caves or realistic animal imagery. Their main job is contacting the spirits of nature in visions or dreamsâ ”an activity that leaves few concrete traces. This means it is difficult to prove that prehistoric humans practiced what we now call shamanism. But the outstanding chimera signs left by prehistoric artists show an ability to identify with animals and suggest an awareness of the transformations that occur in nature. These hybrid signs carry a multiplicity of meanings.

All the worldâ ™s species originated through transformation, or evolution. Contemporary biology demonstrates that humans share genetic sequences with bacteria, mushrooms, worms, bananas, and monkeys. Our very distant ancestors were single-celled organisms. Species are not fixed; they evolve through time. And to signify this, neo-Darwinians use a chimera logo, a fish with legs.

Until recently, rational observers dismissed as â œchildish metaphorsâ the animist beliefs of indigenous peoples regarding human kinship with nature. But now science shows that our kinship with other species is literally true. Every living being, including the tiniest bacterium, is made of proteins built according to instructions encoded in DNA and RNA molecules. Heredity between species is so extensive that 99 percent of mice genes are found in humans.

We are all hybrid beings, resulting from countless transformations. Transformers, one and all.

Chapter 4

Cabin Fever

After traveling in Peru, I returned home to the Jura Mountains, on the border between Switzerland and France. At the time I was mainly living in an old house in the hills heated by a wood-burning stove and a fireplace. It was October, so I stacked wood to prepare for winter. Then I transcribed Amazonian interviews and read books and journals. I also went for runs and hikes in the forest. Some friends expressed worry when I told them I was doing research in the middle of nowhere on the intelligence of other species.

Though I am not a scientistâ ”anthropology being a form of interpretationâ ”I had been reading journals such as *Nature, Scientific American,* and *La Recherche* for several years and had files on subjects such as ants, brains, chimpanzees, dodder plants, embryos, fungi, genes, human evolution, intelligence, â œjunkâ DNA, knowledge, language, mitochondria, nematodes, ova, proteins, reptiles, sperm, tobacco, viruses, whales, X chromosomes, yeast, and zebra fish. I went over these files to assess what scientists had learned in recent years about intelligence in nature.

A wide variety of new research suggests that chimpanzees have culture and use language, dolphins recognize themselves in mirrors, crows make standardized tools, vampire bats reciprocate in food sharing, and parrots answer questions in ways that appear to mean the same to them as they do to people.

Alex, an African Grey parrot living in a lab in Arizona, can count up to six and recognize and name more than one hundred different objects, as well as their color, shape, and texture. When considering two objects, Alex can tell which is bigger or smaller and what attribute is the same or different. If presented with two yellow pencils and asked, â œHow different?â he replies, â œNone.â But when asked, â œHow many?â he answers, â œTwo.â Even when questioned by strangers about objects he has never seen before, Alex answers correctly eight times out of ten. He can also express his desires, squawking, â œCome here!â when demanding attention, or â œWanna go chairâ when bored with his perch. He also turns his back on people and says, â œNo!â when he gets tired of being questioned. Alex, who was picked up at random in a pet store, does not appear to be particularly remarkable among African Grey parrots. Nor do parrots appear to be exceptionally smart birds. The difference between Alex and other talking birds lies in training methods. Alexâ ™s trainer, scientist Irene Pepperberg, used techniques based on what birds do in the wild. Young parrots appear to learn their vocalizations by watching their peers and parents. Pepperberg trained Alex by letting him watch her teach another person. He now performs on cognition tests as well as dolphins and chimpanzees. Alex has a brain the size of a walnut, but he means what he says.

Even creatures with tiny brains have astonishing capacities. For example, leaf-cutter ants, with brains the size of a grain of sugar, practice underground agriculture and use antibiotics wiselyâ ”and appear to have been doing so for fifty million years. Living in South and Central American rain forests, these ants feed themselves by getting around plant defenses with the help of a mushroom. They cut vegetation, scrape away plant antifungal defenses such as the waxy coating of leaves, chew the leafy matter into a pulp, and use it as a substrate on which they grow their fungal crops. In turn, the fungus does away with the insecticide substances contained in the leaves, which it digests, and which are absent from the mushroom tissue eaten by the ants. A leaf-cutter nest is mainly underground, an excavated warren with thousands of chambers filled with gray fungus. Warrens can reach the size of a human living room and house up to eight million ants. The fungus is the antsâ ™ main food, and they make a monoculture of it. This puts their underground farms at the mercy of parasites and pests. One parasite in particular is a devastating species of mold that is found only in ant fungal gardens. Leaf-cutter ants do not just weed, manure, and prune their fungal crops; they also work constantly to keep the parasitic mold in check. To do this, scientists recently discovered, they use *Streptomyces* bacteria, which they carry on specialized parts of their bodies. This particular bacterium is the source of half the antibiotics used in medicine. Ants appear to have been using antibiotics on their fungal crops for millions of years without developing the pathogen resistance that plagues human use of antibiotics. How could they do this without a form of intelligence?

Defining â œintelligenceâ is problematic, and I spent several days looking into the question. I found that intelligence has often been defined in terms of human capacities. Definitions include: â œthe ability to solve problems or to create products that are valued within one or more cultural settings,â or â œa biopsychological potential of our species to process certain kinds of information in certain kinds of ways,â or â œskill in the use of a medium (like computers or symbol systems).â These definitions imply that other species lack intelligence. Other definitions emphasize the multiplicity of intelligencesâ ”linguistic, logical-mathematical, emotional, musical, practical, spatial, and so on. Intelligence has also been defined as the capacity for abstraction. Anthropologists have pointed out that some cultures have no concept for intelligence, while others define it in ways surprising to Westerners, for example in terms of good listening skills, or a strong sense of ethics, or the ability to observe, interpret, and negotiate the social and physical landscape. Intelligence is an elusive concept. In such cases I usually turn to the etymology of words. In its original meaning, intelligence refers to choosing between (inter-legere) and implies the capacity to make decisions.

Winter came. I delved further into the scientific literature on intelligence in nature. No matter how much wood I burned, the nineteenth-century cabin remained cold by contemporary standards. I insulated the windows, which were old and single pane, but the cold still came through. Central heating and the twentieth century had made me soft. Huddling by the fire was often the only option for warmth. I wore layers of clothes including thermal underwear and gloves with holes at the fingertips so I could type. Strangely, I found these circumstances satisfying, because they turned intellectual activity into a physical challenge.

As I reviewed the recent science on the intelligent behavior of organisms, I was struck by its contrast to the biology I had learned in high school in the 1970s. Back then, most scientists seemed to make a point of considering plants and animals as objects devoid of intention. Jacques Monod, one of the founders of molecular biology, wrote in his book *Chance and Necessity:* â œThe cornerstone of the scientific methodâ ¦consists of systematically denying the existence of purpose in nature.â This method considers living beings as if they were mechanical. For example, Monod wrote about bees: â œWe know the hive is â ˜artificial,â ™ in so far as it represents the product of the activity of the bees. But we have good reasons for thinking that this activity is strictly automaticâ ”immediate, but not consciously planned.â

Since Monod, scientific views have evolved. Now bees are no longer considered to be mindless automatons. American biologist Donald Griffin, a pioneer in the study of animal cognition, recently said: â œHoneybees do a lot of learning. They have to learn every day where the food is and then communicate itâ ¦. So the idea that theyâ ™re rigid and a little mechanicalâ ”one of my colleagues at Cornell speaks of it as looking at honeybees as though they were flying toastersâ ”is misleading. Theyâ ™re actually quite complicated. Though itâ ™s very limited compared with what mammals do, itâ ™s not completely different. It seems to me, more likely than not, that there is some sort of continuum extending from the mental world of bees to us.â

Mentalities within the scientific community have changed to the point that Donald Kennedy, the editor in chief of the journal *Science,* declared in 2002: â œAs more and more is learned about the behavior of animals, it becomes for me at least more and more difficult to get closure on a set of properties that are uniquely and especially human, [and] can be defined unambiguously in that way. So, as we learn more and more about the neural and behavioural capacities of animals, I think the zone of what we think of as uniquely human is gradually shrinking. And as we learn more about how their brains work it may well change our attitudes about how different we are from them, thus reducing our sense of being all that special. And that takes me, I must tell you, into a space Iâ ™m not entirely comfortable with. Thereâ ™s this awkward growth of knowledge. It might in the long run change our view of our place in the living world.â

It no longer seems a virtue for scientists to consider animals as automatons or machines. An *awkward growth of knowledge* has occurred. But still, I wondered why the mechanical view of nature held sway for so long over twentieth-century science.

I looked to the history of biology for answers. I went back to English philosopher Francis Bacon, one of the founders of modern science at the beginning of the seventeenth century. Bacon started by critiquing ancient Greek philosopher Aristotle, who claimed that everything in nature behaves to achieve a goal. For Bacon achieving goals is a specifically human activity, and attributing goals to nature misrepresents it as humanlike. Humans fall into the trap known as *teleology* (from the Greek *telos,* meaning end, or aim), because, Bacon argued, we have a misleading tendency to project ourselves onto the world. This is known as *anthropomorphism,* a term derived from two Greek words for *human* and *form,* and meaning the attribution of humanness to the nonhuman. After Bacon it appeared contrary to the scientific method to attribute subjectivity to nature, because scienceâ ™s task is to objectify the natural world. Anthropomorphism became a â œcardinal sinâ for scientists.

French philosopher RenÃ© Descartes went on to claim that animals are machines. In his 1637 book *Discourse on the Method of Rightly Conducting the Reason and Seeking for Truth in the Sciences,* Descartes wrote: â œThis will not seem strange to those who know how many different *automata* or moving machines can be made by the industry of man, without employing in so doing more than a few parts in comparison with the great multitude of bones, muscles, nerves, arteries, veins, or all the other parts that are in the body of each animal. They will consider the body as a machine which, having been made by the hands of God, is incomparably better arranged, and possesses in itself movements which are much more admirable, than any of those which can be invented by manâ ¦. It is also a very remarkable fact that although there are many animals which exhibit more industry than we do in some of their actions, we at the same time observe that they do not manifest any industry at all in many others. Hence the fact that they do better than we do, does not prove that they are endowed with mind, for in this case they would have more mind than any of us, and would surpass us in all other things. It rather shows that they have no mind at all, and that it is nature which acts in them according to the disposition of their organs, just as a clock, which is only composed of wheels and weights, is able to tell the hours and measure the time more correctly than we can do with all our wisdom.â

Descartes wrote in French, and to refer to what animals lacked he used the word *esprit,* meaning both *mind* and *spirit.* Descartes believed that only humans have souls, and thus did not believe that animals â œreallyâ feel pain. He pioneered the practice of vivisection, or the dissection of living animals.

Descartesâ ™ perspective seemed incredible to me. How could anyone seriously believe that a howling animal does not experience pain? But I felt sympathy for Descartes. He wrote in a period when religious authorities executed numerous people on suspicions of â œwitchcraftâ and â œunorthodoxâ thinking. Descartes courageously contributed to wrestling knowledge from the Church and laid the grounds for rationalism. Four centuries later I was free to think what I wanted and use the different advances of science and other forms of knowledge to construct my own understanding of the world. Had Descartes visited me in my cabin, however, I would have argued with him into the night that it makes no sense to view animals as machines devoid of sentience.

Over the last centuries many Western thinkers disagreed with Descartes on this question. English philosopher John Locke thought animals have perception, memory, and reason, but lack abstraction (â œBrutes abstract not,â he wrote). Scottish philosopher David Hume thought that animals can reason and learn from experience, just as humans do. And German philosopher Arthur Schopenhauer believed that animals have understanding and free will. But it took English naturalist Charles Darwin to undermine the view that animals are machines.

Scientists before Darwin had suggested that humans are connected by heredity to other life forms. But in the middle of the nineteenth century, Darwin brought it all together in his search for the natural laws governing biological systems. He traveled around the world for five years on a ship and took a repertory of as many living species as possible. Then he laid out the evidence in his 1859 masterpiece, *On the Origin of Species by Means of Natural Selection,* arguing that living organisms including humans all evolved from a common source. If humans descend from animals, how can animals be machines?

The whole point of Darwinâ ™s theory was that humans have much in common with other life forms. To test his ideas Darwin put animals in front of mirrors to see if they showed signs of recognizing themselves. The apes he tested demonstrated certain forms of self-awareness: They gazed at their reflection in surprise, shifted perspectives to look again, and struck various poses while observing themselves. In his book *The Expression of the Emotions in Man and Animals* (1872), Darwin described animals with self-awareness and emotions. And he thought that even simple creatures like earthworms and ants have intelligence. He wrote: â œA little doseâ ¦of judgment and reason, often comes into play, even in animals very low in the scale of nature.â

Darwin wrote about the mental faculties of ants in his book *The Descent of Man* (1871): â œAnts certainly communicate information to each other, and several unite for the same work, or for games of play. They recognize their fellow-ants after months of absence, and feel sympathy for each other. They build great edifices, keep them clean, close the doors in the evening, and post sentries. They make roads as well as tunnels under rivers, and temporary bridges over them, by clinging together. They collect food for the community, and when an object, too large for entrance, is brought to the nest, they enlarge the door, and afterwards build it up again. They store up seeds, of which they prevent the germination, and which, if damp, are brought up to the surface to dry. They keep aphides and other insects as milk-cows. They go out to battle in regular bands and freely sacrifice their lives for the common weal. They emigrate according to a pre-concerted plan. They capture slaves. They move the eggs of their aphides, as well as their own eggs and cocoons, into warm parts of the nest, in order that they may be quickly hatched; and endless similar facts could be given.â In view of such evidence, Darwin concluded that â œthe mental faculties of man and the lower animals do not differ in kind, though immensely in degree.â

I felt exhilarated reading Darwin. Here was a fellow who traveled to the end of the world in search of knowledge and who delighted in observing all manner of creatures, no matter how small. Darwin rose above centuries of religious belief and argued that humans have kinship with nature. Here was a shaman among scientists.

But Western culture has a long history of setting humans apart from nature. It would take more than a century for the implications of Darwinâ ™s work to sink into the minds of the majority of scientists dealing with animals. In fact, the twentieth century was the heyday of treating animals like machines and conducting experiments on them on a massive scale.

Why?

As a child of the twentieth century and of Western culture, I wanted to understand the origin of our blinders regarding nature. I paced around the cabin for days, thinking and listening to dissonant music. Snowstorms came and went. I was happy to be snowed in.

The twentieth century marked the triumph of machine-driven industry. This influenced the way scientists considered nature. But intellectual conditions also played a part. A crucial development occurred when British zoologist and psychologist C. Lloyd Morgan proposed the following rule for those who study animal behavior: â œIn no case may we interpret an action as the outcome of the exercise of a higher psychical faculty, if it can be interpreted as the outcome of the exercise of one which stands lower in the psychological scale.â This became known as Morganâ ™s canon. It was based on the widely held principle of parsimony, or Occamâ ™s razor, which states that the simplest explanation is to be preferred when several possible explanations exist. For decades, psychologists, biologists, linguists, and philosophers used Morganâ ™s canon to deny the mental experiences of animals.

Some biologists resisted this view, however. For example, English biologist Julian Huxley wrote in his *Essay on Bird Mind* (1923): â œThere is a large school today who assert that animals are â ˜mere machines.â ™ Machines they may be: it is the qualification which does not fit. I suppose that by saying â ˜mereâ ™ machines it is meant to imply that they have the soulless, steely quality of a machine which goes when it is set going, stops when another lever is turned, acts only in obedience to outer stimuli, and is in fact unemotionalâ ”a bundle of operations without any quality meriting the name of a self. It is true that the further we push our analysis of animal behavior, the more we find it composed of a series of automatismsâ ¦. the more we have cause to deny to animals the possession of anything deserving the name of reason, ideals, or abstract thought. The more, in fact, do they appear to us as mechanisms (which is a much better word than machines, since this latter carries with it definite connotations of metal or wood, electricity or steam). They are mechanisms, because their mode of operation is regular; but they differ from any other type of mechanism known to us in that their working isâ ”to put it in the most non-committal wayâ ”accompanied by emotion.â

Japanese scientists went further. Coming from a culture that places humans and animals on the same plane, they tend not to subscribe to a mechanical view of nature. Japan generally has a Chinese-modified Buddhist cultural background in which humans, animals, and gods exist on the same plane and can turn into one another, and in which humans are not considered to be the only ones with souls. In the 1950s, Japanese researchers pioneered the study of the mental lives of primates by reporting observations about the animalsâ ™ motives, personalities, and lives. Japanese primatologists came up with a new way of observing animals in the wild. It consisted of looking closely and quietly without interfering, and identifying monkeys individually and following them around for long periods. This revealed what relationships each individual monkey has with others. The Japanese scientists found that kinship is important for monkeys. They also observed a macaque monkey learning how to dip sweet potatoes into a stream in order to wash them; then they documented how this learned behavior spread through the entire troupe. They called this â œpreculture.â Japanese scientists also first reported that monkeys practice infanticide, and that chimpanzees use stone tools. For several decades, these reports, which relate to activities previously thought to be exclusively human, were either ignored by Western scientists or dismissed as highly anthropomorphic. But now the Japanese approach to doing fieldwork among primates has become the scientific standard. By treating primates like humans, Japanese primatologists moved leaps and bounds ahead of their Western colleagues. By treating animals with intelligence, they found intelligence.

Through most of the twentieth century, Western science was dominated by the view that animals are mechanical. Some scientists went so far as to consider animals as interchangeable â œstimulus-response machines.â As B. F. Skinner, one of the founders of behaviorism, wrote: â œPigeon, rat, monkey, which is which? It doesnâ ™t matter.â

Even an open-minded biological commentator such as Lewis Thomas wrote in 1974: â œA solitary ant, afield, cannot be considered to have much of anything on his mind; indeed, with only a few neurons strung together by fibers, he canâ ™t be imagined to have a mind at all, much less a thought. He is more like a ganglion on legs.â

How had we come from Darwin, who admired the mental faculties of ants, to this? I turned this question over in my mind for days. It was as if most Western biologists had fallen into a mechanical trance for close to a century, out of which they were only just emerging. I did not fully understand why things had happened this way. But I did feel relieved that science was changing and revealing intelligence in nature once again. And this confirmed some of the most ancient beliefs of indigenous people.

I had spent years working with indigenous Amazonian people for the recognition of their territories and support for their bilingual education programs. Their ways of knowing can be hard for rationalists to grasp. But they had impressed me as pertinent. Now I wanted to see if science and indigenous knowledge could be bridged, if only to reconcile them in my mind. Bringing these two approaches together on the question of intelligence in nature could lead to fresh insights about how life works, and to a richer understanding of ourselves and of other species. This would be precious knowledge in todayâ ™s world.

By the end of the winter, several things seemed clear to me. Scientists from many countries have set themselves on the trail of intelligence in nature, and I wanted to learn more about what they were discovering. Science has gone through profound changes in recent decades, and scientists are starting to argue against sacrosanct principles such as Occamâ ™s razor. Some scientists are realizing that there is little evidence that nature is simple, or that simple accounts are more likely than complex ones to be true. A few scientists are even starting to argue in favor of anthropomorphism. For example, primatologist Frans de Waal wrote in 2001: â œCloseness to animals creates the desire to understand them, and not just a little piece of them, but the *whole* animal. It makes us wonder what goes on in their heads even though we fully realize that the answer can only be approximated. We employ all available weapons in this endeavor, including extrapolations from human behavior. Consequently, anthropomorphism is not only inevitable, it is a powerful tool.â

One day, the sun came out and the snow began to thaw. I went for a run and soaked up the rays and warmth with gusto. As I made my way along the trail up in the pastures next to the woods, my eyes caught a strange sight. A large pink earthworm was crawling very slowly across the snow, coming from an earth bank exposed to the sun. I stopped to observe it for a while. Like me, it had made its way out into the first warmth of the year and appeared to be going somewhere.

Chapter 5

Insect Minds

It was mid-May, and spring was turning to summer. I made a beeline for the South of France. Coming from the Swiss hills, I felt hot for the first time that year. I had an appointment at the University of Toulouse with Martin Giurfa, a scientist who had recently demonstrated that bees can handle abstract concepts.

The work by Giurfa and his colleagues had caught my attention in a scientific journal. They reported on an experiment in which they exposed honeybees to a simple Y-shaped maze. The entrance to the maze was marked with a particular symbol, such as the color blue. A bee flying through the entrance encountered a branching pathway, or â œdecision chamber,â where it could choose between paths. One path was marked with the color blue, the other with the color yellow. Bees that followed the blue-marked path discovered at its end a vial filled with sugared solution. Bees that took the yellow path received no reward. The bees soon learned that sugar lay at the end of the route marked with the same symbol as the one marking the outside entrance. â œSameâ equals â œsugar,â in other words. In a subsequent experiment, the opening to the maze was marked by a different symbol, such as horizontal dark lines. In that case, on entering the decision chamber, the bees reencountered the two pathways, which were marked this time not with colors but with linesâ ”vertical lines on one path, horizontal lines on the other. The bees passed with flying colors, heading straight for the pattern that matched what they saw at the entrance. Other experiments revealed that the bees could also transfer their knowledge across the senses: Bees that learned about sameness by matching odors were able to apply the concept to visual signs. Though bees have brains the size of pinheads, they can master abstract rules.

This research falsified the notion that â œbrutes abstract not.â It also showed that small brains do not hinder thought. I felt moved to meet the person behind this research and hear his point of view.

The University of Toulouse has a sprawling campus. Despite the signs and pathways, it took me half an hour to find the Laboratoire dâ ™Ethologie et de Cognition Animale. It was located in a four-story building that was being renovated. As I walked in, drills resonated from the floors above.

Martin Giurfa had recently been chosen by Franceâ ™s National Center for Scientific Research (CNRS) to head their new center for the study of animal cognition. We had not met previously or spoken on the phone and had only communicated by electronic mail. As I knocked on his door, I considered the possibility that he might wear a white lab coat and speak with detachment.

Instead I found a youngish-looking man sitting in front of a computer at a comfortable desk, wearing a green-checked shirt with short sleeves. The room was filled with plants, and the blinds were down to fend off the sunlight. Giurfa wore wire-rimmed glasses, and his hair was dark and short. He smiled and invited me to sit down in the chair next to his desk. He spoke English with an indeterminate accent. I asked where he was from. He said that he was born in Argentina and that his family had come from Italy.

As a cultural hybrid, I felt at ease with Giurfa. I was curious to know how he had come to develop an interest in biology. â œSince I can remember, I have loved animals,â he replied. â œI was always fascinated by the observation and the magic of the living machine. But I have just made a big mistake: I used the term *machine* to describe living organisms. That is exactly the opposite of what I think. In fact they are *not* machines. But I was always fascinated by looking at the living organism, from the point of view of the exterior observer, seeing how it moves, takes decisions, and so on. It was always fascinating for me how a wasp decides to go here and not there, how a wasp finds its way home and identifies the nest, how a bee forages from flower to flower, always going from the flowers of one species to the same species.â As a child, Giurfa kept different animals as pets, including insects, water snakes, and a boa constrictorâ ”much to his motherâ ™s dismay.

Giurfa explained that he had referred to bees as â œmachinesâ because that was how he used to think about them in the past. But the more he understood how animals make decisions and learn, the more he had to admit that they do not act mechanically. His view started to change in 1990, when he went to Berlin and began working in a leading neurobiology institute, alongside sixty colleagues from different fields of science who were all studying memory and learning in honeybees. It soon dawned on him that bees learn in an intelligent way. For example, their capacity to navigate surpasses our own: â œIf I take you to a distant part of the campus,â he said, â œand release you there, you wonâ ™t find your way easily back here. But bees can. How they do it is the question. This is why I started to think about cognition in invertebrates, which, of course, at the time, was considered a kind of contradiction in terms. People said, â ˜You are absolutely crazy for raising this kind of question. How could you think that invertebrates could have this kind of intelligent behavior?â ™ That is what people were saying to me.â

â œWhat did you make of that resistance?â

â œI simply didnâ ™t care about it. That was an advantage in Berlin; you had intellectual freedom to raise questions and perform research work.â

I wanted to know why some of his colleagues were so opposed to studying cognition in invertebrates. â œBasically,â he said, â œit was the dominating view, that you can find even now in some people, for instance in researchers working with vertebrates. They still think that invertebrates are small robots, that they are simple machines, reflex machines, you know, like Pavlov machines, or Skinner machines. Simply like hitting a hammer on your knee and having a jerk reaction. They say that invertebrates have to be simple like that.â

Though Giurfa was critical of the robotic view of insects, he admitted that it had helped advance the study of insect movements and behaviors. â œConsidering insects as simple robots has, for instance, stimulated the creation of machines like the Mars explorer, which was inspired by how insects move their legs and so on. This point of view is of course short minded, if you will, but at least it had this positive aspect.â

Someone knocked on the door, interrupting the conversation. Giurfa had a brief exchange in French with a colleague, and I noticed that he spoke with greater fluency than in English. Once he was done, I renewed the conversation in French and we continued in that language. I asked whether there had been resistance to his recent work on the capacity of bees to handle abstract concepts. He said he was confident that the experiments were well conducted and that the results, which were published in the journal *Nature,* could not be attacked scientifically. But he did mention resistance from a group of researchers at a nearby center for the study of primate cognition. They contacted Giurfa to say that they had tested monkeys on the same task and found that certain species could not do it; therefore, they did not believe it was possible bees could. Giurfa said this kind of reaction occurred less and less frequently.

In his view, when animals are found not to accomplish a given task, this is not proof of their stupidity. â œIn most cases, the problem lies with the person conducting the experiment and involves incapacity in the researcher to develop experiments that pose the problem correctly and allow one to answer it properly. If you will, a negative result shows nothing, in the final analysis. A positive result shows something. But when an animal cannot do something, the question remains: Is it incapable of doing it or have I not been clever enough in my research concepts and experimental design?â

â œSo, would you say that the problem for the moment is not that nature lacks intelligence but that researchers studying it do?â I asked.

â œThat is one of the problems, certainly. I think we are a long way from having made a kind of mental jump which would allow us to ask certain questions.â

I had read several recent books that discounted the intelligence of individual insects, referring instead to â œswarm intelligence.â The idea seemed to be that bees were mindless robots programmed according to a series of simple rules, and that intelligent behavior emerged from the interactions of the mindless parts. â œEmergenceâ was a concept that was used to explain how â œdimwittedâ individuals could appear to act intelligently. I asked Giurfa what he thought about â œswarm intelligenceâ and â œemergence.â

He replied that these concepts could explain some behaviors, but not all, and that it was important to distinguish between group behavior and the intelligence of the individual. â œAll these studies on emergent properties are certainly interesting, and they are a good challenge for me. I like these studies because they make me rethink my own research from another perspective.â He said it was important not to take his own point of view too far by claiming, for example, that bees are capable of the highest and most flexible forms of learning. In fact, bees sometimes behave stupidly. If placed in a maze with a glass cover, for example, they perform as well as rats up to the point of reaching the food reward, but they are incapable of turning around and going back to where they have come from. Once bees eat, they are rigidly programmed to fly upward. Bees in a glass-covered maze bang against the glass cover, trying to gain altitude, until they die. They are programmed according to a simple rule: To get back to the hive, first go upward, to where light intensity is greatest, toward the sky. So, Giurfa said, it is important to avoid exaggerating the plasticity of bee intelligence. Both principles operate: There are simple rules and emergent properties on the one hand, and plastic cognition on the other. â œThatâ ™s why itâ ™s a challenge, because it obliges me to think about the problems in my system from another perspective as well.â

Scientists often use the concept of â œinstinctâ when explaining the capacities of animals. I asked Giurfa if he found it useful in his work. He said that he had started his work in Berlin by studying a question related to bee instinct, looking into whether or not bees have information encoded in their brains when they take their first exploratory flight. Giurfa built a large apiary containing a small beehive in which all external conditions are controlled and went on to demonstrate that bees spontaneously prefer certain colors, in particular very intense blue and yellow. These colors correspond to the flowers richest in nectar. So instinct exists, Giurfa said, and is a useful concept. But Giurfa also found that bees can modify their instinct according to what they learn about the world. In the controlled environment he constructed, Giurfa arranged for pollen to be associated with other colors and found that bees can modify their color instincts. â œWe see the incredible plasticity of the system,â he said. â œThis means that they go into nature equipped with instinctive information, which is not rigid, and which they can forget or put aside on the basis of personal experience, meaning to say on the basis of learning.â

A loud hammering echoed through the ceiling. Upstairs, workers were bringing down a wall. Toulouse University was remodeling its Animal Behavior Department, turning it into a â œlaboratory of animal cognition.â I took this as a sign of the times. Science is opening up to the intelligence of other species, and this is bringing down university walls, literally.

Giurfa turned to his computer and summoned up a full-screen image of the internal organization of the bee brain. He explained that a key part of their research involves looking into bee brains in search of the â œneuronal substrateâ of a given behavior. For scientists, the great advantage of the bee brain is that it can handle complex mental tasks with less than a million neurons. This simplifies research. Working with brain-imaging techniques, Giurfa and his colleagues mapped which parts of the bee brain are active when the animal learns about the smell of the outside world. Their research revealed the existence of a sensory-integration center called the â œmushroom body,â which is made of 170,000 densely packed neurons. This central component of the bee brain receives sensory input and directs behaviorsâ ”such as when bees dance symbolically to communicate information about the location of pollen-laden flowers, or navigate over long distances according to the sunâ ™s position in the sky, or estimate the quality of potential nest sites.

Giurfa explained that they looked into the bee brain using a technique known as calcium imaging. Given that active neurons exchange calcium, one can open the skull of a living bee and bathe its brain in fluorescent substances that latch onto calcium and reveal the active parts of the brain. â œThis is another advantage of invertebrates,â he said. â œThis process does not affect the animal. Invertebrates are enveloped in a capsule; their whole body is a capsule that is not innervated. It is very hard for us to imagine, but that is how it is. Imagine that instead of having skin, which is sensitive because it is innervated and filled with nerve endings, we had our internal system in armor.â

â œSo the nerves stop with the brain?â

â œExactly. If you open it, if you make a small hole in a beeâ ™s head, it is just like taking a helmet off. You do not hurt it because it is not innervated. The outside part of the insect which you can see is like a protection shell.â

I viewed pain as an experience humans probably share with animals. I have passed several gallstones, and know that pain has to do with the deep wiring of my body. I know just how paralyzing and excruciating it can be when raw nerves inside the body are scraped. Pain seems to be an undesirable experience one can have when one is equipped with a central nervous system. I knew nothing about pain among insects, but I figured that if their brains can handle abstraction, they can probably handle pain as well. I asked Giurfa if he thought bees feel pain. He said, â œIf you hurt a muscle, then, yes, you hurt the animal, but if you just remove a bit of shell, you do not hurt it. So you can delicately expose the brain, by fastening the bee in a tube, and you can look at what is going on.â

Pointing at the map of the bee brain, he showed me the â œolfactory pathway.â On the tip of a beeâ ™s antennas are olfactory receptors (corresponding to the mucus membrane inside the human nose), which feed chemo-electrical information into nerves leading to two small grapelike structures at the base of the brain (similar in shape to our own olfactory bulb). From there, wirelike neurons lead to the mushroom body, which processes the different inputs.

Giurfa and his colleague Randolf Menzel recently described the â œcognitive architecture of the honeybee minibrainâ as a network of independent units, the â œmodules of an insect mind.â Each module treats information from a specific input, such as smell. The different inputs are then combined in a central locus, the mushroom body, where â œcontext-dependent decisionsâ are reached. This enables honeybees to â œextract the logical structure of the world.â

Bees go out into the world equipped with a tiny brain and learn about their environment in next to no time. They have a lifespan of only two or three weeks. They seem ready to learn as soon as they hatch.

Some of Giurfaâ ™s graduate students were running an experiment next door. He suggested we go and check their work. I followed him out of his office and found three students sitting at a white table gathered around an odd-looking deviceâ ”a blue metal plate with a copper cartridge sticking out of one end. A bee was strapped into the cartridge. An array of small tubes was directed at its face. The graduate student conducting the experiment held a toothpick in his hand. He explained that when the antenna of a hungry bee is touched by a toothpick dipped in sugared solution, a reflex always occurs, causing the bee to stick out its tongue in a jerk reaction comparable to the reflex of a knee hit by a hammer. Giurfa explained that one could present an odor immediately before the sugar reward, and teach the bee to form an association that, in subsequent tests, causes the odor, rather than the sweetened toothpick, to release the tongue. This shows bees can learn about smell; it also reveals which parts of their brains are active when they do so. Bees, it turns out, can detect odors with greater sensitivity than dogs.

I looked closely at the bee in the cartridge. It was strapped in with blue tape. It could only move its antennas and tongue. Its head was glued to the back of the tube.

I chatted for a while with the graduate students. They were from Germany and said, speaking in English, that they loved Toulouse, which is near the Mediterranean, the Pyrenees, and the Atlantic, all at once. But they said it was more difficult to concentrate on science here; in Berlin, where it was â œgray and rainy all year,â they found it easier to work; here, they wanted to go on vacation all the time.

I focused once again on the bee. Spending an hour strapped in a bullet was a long time from a beeâ ™s perspective. It did not seem very comfortable. I inquired about its fate after the experiment. Giurfa explained that the bees they tested in this fashion had to be killed, because otherwise they would return to the hive and falsify subsequent trials.

The bee I was observing had already experienced one nonrewarded odor and one rewarded one. Now it was about to receive the rewarded odor for the second time. We gathered around closely to see if it had learned something. The odor came out of the tube, and presto, the bee shot out its tongue. It had made the connection.

At that moment, I felt jubilation, and kinship with the bee. Like some humans, it was a fast learner. I asked Giurfa whether he thought finding intelligence in insects means they deserve better treatment. He said he agreed with the question and explained that there was research he would never do, in particular inserting electrodes into bee brains. He had not heard of animal-rights activists opposing research on invertebrates, though at the University in Berlin there had been much resistance to scientists studying vertebrate neurobiology. â œAt that time we chose the invertebrates exactly because we did not want to offend the sensibilities of some students,â he said. â œIf you want to study biology of the whole, and see all the possible fields it has, you have to see and try these experimental techniques and approaches. Being an experimental biologist, I could never approve of thinking that everything could be done with simulations and models.â He added that he would not perform the experiments he did on bees on cats, dogs, or apes, due to his â œparticular personal sensibility,â which he knew was â œjust an anthropocentric point of view.â

Though he refused to put electrodes into the brain of a living bee, he admitted that exposing the beesâ ™ brains and submitting them to calcium imaging was injurious to them, and would lead to their being killed. I returned to the question of whether bees feel pain. He laughed and called it a difficult question. In labs in South America, he said, scientists have shown that bee nervous systems produce opioids, presumably to induce analgesia. However, given that bees and humans are separated by hundreds of millions of years of evolution, he questioned whether the human concept of â œpainâ applies to bees. In his view, no one knows the answer.

I asked about the overall implications of his work on bee cognition. He said it shows that brain size is irrelevant when it comes to the capacity of performing highly demanding cognitive tasks. He also said it is time to do away with the arbitrary barrier that scientists have erected between vertebrate â œlearners,â such as apes, pigeons, dogs, cats, dolphins, and humans, and all other â œnoncognitive organisms.â

We spent half an hour with the students, then left them to their painstaking research and went out to lunch at a nearby restaurant. We talked about several subjects. He asked me about the Peruvian Amazon, where he had traveled. I asked him about his intellectual influences. He spoke of his thesis advisor in Argentina, and of his love for bees.

At one point I asked for his view on plant intelligence. He said the problem with plants is that they do not move, which makes it difficult to perform scientific experiments on them. I mentioned the parasitic dodder plant, which roams about and correctly gauges the nutritional content of other plants. He immediately suggested research questions about dodder. Can it learn to avoid certain substrates through negative reinforcements? If it demonstrates a capacity to learn, at what level of its cellular structure does the learning establish itself? â œWhen you talk of learning, or cognition, the problem is that by definition you need a change of behavior resulting from individual experience,â he said. â œThat is the only way to show that learning, or memory, has occurred. This means that all the approaches based on molecular biologyâ ”finding such-and-such a receptor or neuron Xâ ”are of no use whatsoever unless you demonstrate a change in behavior. When a given behavior changes, you can go and look into the box and find the molecules. But if you go looking for molecules without the change in behavior, you can say nothing. Learning manifests itself once the individualâ ™s behavior changes. Changes at the cellular level are not necessarily relevant to this. And so, with plants, you need a visible change of behavior. Thatâ ™s the challenge. But with the plant you mentioned, which moves, someone should be able to find something.â

I asked him to comment further on how other scientists had received his research. He said that when he travels and presents his work, it is not questioned much. Rather, it leads other scientists to ask themselves questions they have not previously considered. He regards this as a success, even if his work does not provide answers to his main questions.

When asked if he could suggest any other scientists doing work on intelligence in nature, he mentioned an Austrian biologist studying cognition in amoebas. He also suggested several Japanese research teams: one working on color vision among insects, another on cricket olfaction, and a third on butterfly neurology. â œGo to Japan,â he said.

I left Martin Giurfa in front of his laboratory in the early afternoon. We promised to stay in touch. I felt elated, but also a bit dazed. I had come half expecting to meet a cold scientist. Instead I found a fellow who encouraged me to keep looking into intelligence in nature. I felt as if he had given me a license to continue deeper into unknown territory.

Chapter 6

PREDATORS

I returned to the Jura Mountains and spent the following months reading and thinking about plants and animals. Martin Giurfa had made me look into the relationship between movement and intelligence. It is true that some observers claim that plants lack intelligence because they do not see them move. But this is an optical illusion caused by the different timescales we operate on. Plants, in fact, do move.

Most plants move slowly, but some plants move fast even in human terms. A Venus flytrap can snap its leafy lobes shut in a third of a second to catch insects lured by its nectar. The flytrap is a predatory plant that eats flesh by secreting digestive juices and dissolving its prey. Its reflexes are triggered by electrical signals similar to those that run along our own nerves.

Unlike the Venus flytrap, most plants do not eat animals. Instead they take nutrition from sun and soil. Plants are also eaten in large amounts, being the basic element in all food chains. They are clearly successful at surviving, as they make up 99 percent of the mass of Earthâ ™s living organisms.

Movement can be a criterion of intelligence among animals, but it does not apply to plants. They eat freely available sunlight and soil nutrients, so they mainly do not need to move from one place to another. Those among us who lack this ability are obliged to move about in search of food. Animals are, by definition, organisms that move to feed themselves. Animals are animate. They move.

Over the course of evolution, animals with efficient nervous systems have had an edge over their competitors. A nervous system that conducts information down to the muscles in a matter of milliseconds, rather than seconds, helps avoid being eaten. We use our brains to escape from predators. And as predators, we use them to catch our prey. This neurological arms race between animal predators and animal prey has certainly contributed to the development of brains such as our own.

But plants have not remained inactive. They may appear to sit around merely absorbing sunlight and being eaten in large amounts, but these brainless organisms have developed thousands of chemicals to try to stop themselves from being eaten. Plants have contributed to the arms race of evolution in the domain of chemistry. Unlike animals, they never had to develop movement or nervous systems to avoid predation.

We humans operate on a very rapid timescale compared to most plants. To us, plants can look stupid just sitting there. In fact, the term *vegetable* is an insult when applied to humans. According to the *Concise Oxford Dictionary,* it means â œa person who is incapable of normal mental or physical activity, especially through brain damage; a person with a dull or inactive life.â We have animal prejudices against vegetables, and they come out in our vocabularies.

I wanted to reconsider things from the start and try to move away from my own prejudices. As an animal, I wanted to understand animals. For starters, I learned that not all animals have brains. The sponge, for example, does not even have nerve cells. It lives attached to the sea bottom, or to other objects. The natural sponge that can be purchased in a store is the skeleton that supports the sponge animal. Inside this skeleton, the body of the living sponge consists of a kind of perforated stomach lined by whiplike cells which create currents that draw in water and food particles. A four-inch sponge can filter one hundred liters per day in this way. Sitting stuck to a rock at the bottom of the ocean, a sponge just sucks in its food. Zoologists recently discovered that one type of sponge can respond to potential danger by generating electrical impulses similar to those that streak through the nerves of other animals, including humans. Electrical signals disseminate through the sponge body via a network of fine strands of cytoplasm, which are not divided into cells. The sponge uses these signals to shut down the intake mechanism when the water around it becomes murky with particles that would otherwise clog its pores. These electrical signals are part of a decision-making system that allows the sponge to gauge and exploit the world around it. Though sponges are brainless and nerveless animals, they appear to make correct decisions on a regular basis.

The hydra is another brainless, headless, and sedentary animal that lives in water. It looks like a thin, translucent tube about an inch long and has a nervous system called a nerve net, which crisscrosses its body without forming a particular concentration. The hydra lives attached to vegetation by the base of its tubular body. The bottom of the tube is closed, and an opening at the upper end both engulfs food and rejects residue. Around this opening is a circlet of retractable tentacles that sting and catch other small invertebrate animals such as crustaceans. When a hydra detects a prey, it extends its tentacles and reaches out to grasp it. How it carries out this precise action with no brain is not known. Studies reveal that the animalâ ™s nerve net concentrates around its mouth area. This suggests that the earliest heads appeared about 700 million years ago in hydralike organisms that may have been the common ancestors of species from snails to humans. The early head was simply a net of nerve cells at the mouth of the organism. This concentration of neurons close to the mouth shows how important active feeding is for animals. We exist in our current shape, with heads containing brains close to our mouths, as a legacy of this.

I scratched my head thinking about the fact that my brain is close to my mouth. I used my predator brain to think about the long line of predators that had led to me. I could see an endless queue of mouthed ancestors stretching back hundreds of millions of years, snapping their teeth and laughing.

I looked into the origin of central nervous systems. They first developed in small invertebrates like nematode worms. The present-day nematode *Caernohabditis elegans* looks like a mere speck to the naked eye. It has a body made up of fewer than one thousand cells, some three hundred of which are neurons that form a ring-shaped brain around the digestive tube not far from the mouth. The nematode brain, which is among the simplest known, is shaped like a saintâ ™s halo. Centralized nervous systems have shorter and denser connections between neurons. This makes for quicker reactions to changes in the environment and for more complex behaviors.

The brown garden snail *Helix aspersa* has a central nervous system containing only a few thousand neurons. This is not much, considering it has a body the size of a walnut. Consequently, nervous signals take time to travel through the snailâ ™s body, and its muscles can take several seconds to react to an outside stimulus. In fact snails perceive the world in slow motion. But this does not mean they make incorrect decisions. Snails are among the worldâ ™s most successful predators. There are about 65,000 species of snails, living in oceans, fresh water, and on land, in many different kinds of climates and environments. Snails are not stupid, but slow and efficient at what they do.

Octopuses have the largest brains among invertebrates, and scientists have noted their intelligence. Octopuses can run mazes, escape from locked tanks, break into other tanks and steal lobsters, open jars to get at crabs, disguise themselves, and even get angry and turn red.

They have half a billion neuronsâ ™ worth of brain power, which is about two hundred times less than ourselves, but a great deal more than snails. Octopuses are adept at finding food in concealed placesâ ”a skill usually associated with big-brained vertebrates such as bears, pigs, and humans. Octopuses camouflage themselves by gauging their environment and, in a fraction of a second, transforming their body shape and the color, pattern, and texture of their skin. Octopuses are wily transformers.

Vertebrates include fish, amphibians, reptiles, birds, and mammals. We vertebrates have internal skeletons that allow us to achieve larger size than most other creatures. And we have backbones and skulls that partly enclose our central nervous systems, providing secure housing for eyes, ears, olfactory senses, and brains. This makes it easier to respond to the environment. But lacking a backbone does not make invertebrates stupid. Octopuses may be spineless, but they can run mazes as successfully as rats.

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INTRIGUED BY THE CAPACITIES of invertebrates, I went to a zoology department at a Swiss university near where I live and asked if somebody could show me a nematode worm. I wanted to look at a living *Caenorhabditis elegans* through a microscope. The people at the zoology department were not used to dealing with such requests. After all, what business did an anthropologist have wanting to see a nematode? I explained I was writing a book about intelligence in nature and wished to see with my own eyes an invertebrate with a simple nervous system. My request was granted, and I was asked to wait.

On one of the walls in the corridor of the Zoology Department, there was a diagram of the complete body plan of a nematode. Each one of its 959 cells was mapped out in detail. A nematode is barely visible to the naked eye, but it is a complete animal, with skin, brain, mouth, digestive tract, reproductive tract including eggs and sperm, and anus. Nematodes are among the animals that scientists have most studied. They are easy to keep in vast quantities and they reproduce very quickly. And they have transparent skin, which makes it possible to look into their living bodies with a microscope and see their organs function. They also have transparent eggshells, so it is possible to watch their embryos develop.

Nematodes have brains that respond to taste, smell, temperature, and touch. And their neurons send one another an array of chemical signals including serotonin, which is a neurotransmitter that human brains also use. I may have several hundred million times more neurons than a nematode, but as a biological organism I share fundamental commonalities with it. Standing in the corridor looking at the wormâ ™s body plan, I thought of myself as a kind of snaky organism with limbs. As a vertebrate, I differ from a worm in that I have a backbone and a brain encased in a skull. But like a nematodeâ ”and like most other animalsâ ”the bulk of my nerve cells is situated close to my mouth, and I have a long digestive tract. At the core of my being, there is a snakelike tube stretching from mouth to anus.

Nematodes eat bacteria that they find in the soil. All animals feed on other organisms. Even vegetarians prey on plants. You cannot eat a carrot without killing it. Whether a vegetarian diet of plants is more ethical than an omnivorous one is a matter of opinion. I know I am a predator.

Putting an end to my reverie, a woman walked up to me and introduced herself as a geneticist working with nematodes. Her name was Monique Zetka. She came from the Czech Republic. We spoke in English. She was willing to interrupt her work to show me some nematodes.

I followed her into her office and asked about her work. She explained how she microinjected DNA into nematode gonads in order to induce mutations in their eggs. She had several nematodes stuck on an oily slide and invited me to sit down at the microscope to take a look.

Once I got the swing of the apparatus, I focused on a single worm. The nematode was alive and moving. It looked like a transparent, Byzantine snake. Its internal organs had the intricacy of a racing-car engine, and it moved like a ballerina, ending each sideways weave with a flick at the tip of its body. I understood more clearly why the nematodeâ ™s scientific name includes the Latin word for elegant. I admired the nematodeâ ™s beauty for several minutes, feeling amazed that a creature with a brain of only three hundred neurons could move with such grace.

I found the experience thrilling. I turned to Monique Zetka and thanked her sincerely. As the quality of nematodes is not a frequently discussed subject, and as some people get uneasy taking such tiny creatures seriously, I asked with some hesitancy whether she *liked* nematodes.

She seemed embarrassed by the question and simply said, â œThey are pretty nice.â
Scientists sometimes view their business as keeping a cold gaze in the face of natureâ ™s elegance and beauty. I thanked her again and let her get on with her work.

I tried discussing my newfound enthusiasm for invertebrates with people around me, but often they just laughed. Many Westerners place themselves above â œlowlyâ creatures such as nematodes. But humans are part of nature. Like so many other animals, we have eyes, noses, ears, mouths, teeth, brains, digestive tracts, skin, gonads, and so on. We are affiliated to even the simplest creatures.

The first animals were invertebrates. Animals with backbones and skulls only appeared about 500 million years ago. First came fish, then amphibians, reptiles, birds, and mammals. We humans are mammals. We belong to the order of primates, which includes marmosets, monkeys, apes, and chimpanzees.

Humans have several distinctive features, the most obvious of which is that we are the only living primates who walk full-time on two legs. According to the fossil record, some of the first bipedal primates belonged to a now-defunct genus called *Australopithecus.* These precursors of humanity lived about three and a half million years ago and had brains one-third the size of our own. Apart from their near-human posture, they were very much like chimpanzees, with similar diets and similar brain size. The first true hominids, commonly known as *Homo habilis,* appeared about two million years ago. They stood upright and had brains half the size of our own. Since then, hominid brains have continued to expand.

The fossil record is patchy and hard to interpret. Paleontologists do not agree on many details. When did the first *Homo sapiens* appear? Some believe that the roots of our species might extend back over four hundred thousand years. Others think that our immediate ancestors were a separate African species called *Homo rhodesiensis,* and that one should only apply the label *Homo sapiens* to fossils less than two hundred thousand years old. Some paleontologists believe that there have been different varieties of archaic *Homo sapiens,* including *Homo rhodesiensis, Homo antecesor,* and *Homo heidelbergensis,* from whom both modern humans and Neanderthals derived. Others view Neanderthals as an entirely separate offshoot of *Homo rhodesiensis.*

Our stocky Neanderthal cousins lived mainly in Europe and had a brain volume that was slightly superior to our own. Like us, they buried their dead, made musical instruments, and produced efficient hunting tools. Neanderthals were serious predators. Analysis of their fossilized bones reveals that they had a heavy meat diet. Nevertheless, Neanderthals were also quite different from us. Their skulls were oval shaped, not round. Their foreheads were sunken rather than flat. Their chins were also sunken, whereas our own are pointed.

The fossil record suggests that anatomically modern humans, or *homo sapiens sapiens,* emerged in Africa only about one hundred and fifty thousand years ago. This represents about seven thousand biological generations, and shows that we are a very young species. The word *sapiens* means â œwiseâ in Latin. Whether this label truly corresponds to humans remains to be determined.

I found it fruitful thinking of humans as a species. It seemed clear that our great strength is being able to adapt to a wide variety of environments and circumstances. The descendants of the small band of humans that left Africa spread out across the world and populated it. From the Arctic to the deserts of Australia and the rain forests of the Amazon, they learned to exploit the plants and animals in each new environment they entered. Humans have long perpetrated ecological depredation. Species that were easy to hunt tended to disappear shortly after humans arrived in a given area. The fossil record indicates this clearly in places such Madagascar, New Zealand, and Australia. Like lions and wolves, humans are social predators. And we are an invasive species. Our outstanding capacity of adaptation makes us the most dangerous of all macroscopic predators currently stalking the earth.

Archaeologists have compared human campsites to those of Neanderthals living at the same time in the same region. Our ancestors made sophisticated traps and carved fine tools, not only out of stone and wood but also out of bone and antler. They carved bones into needles, which enabled them to sew clothes. Neanderthals probably lacked the capacity to make warm clothes. Our species cohabited the earth with Neanderthals for more than one hundred thousand years, and even traded with them in some cases. But there were four major glaciations during this period, and the Neanderthals did not survive. Paleontologists now think that their mysterious disappearance twenty thousand years ago is best explained by their incapacity to adapt to a changing environment.

Homo sapiens sapiens has a vertiginous trajectory. The Cro-Magnon artists who painted Lascaux, the prehistoric cave in southwest France, lived less than a thousand generations ago. They were humans just like usâ ”but they had neither electricity nor sophisticated technology. Now humans have developed indoor plumbing, washing machines, spacecraft, computers, and an understanding of the intricate workings of biology.

Who are we? We have skulls and backbones, just like other vertebrate animals. Everything indicates that we are animals. Yet we do many things that animals cannot, such as write books, debate the meaning of words, turn trees into paper, study invertebrates with microscopes, equip jaguars with radio collars and track them, ride bicycles, fly planes, pilot submarines, travel to the moon and back, make wine from grapes, smoke tobacco, manipulate DNA molecules, build nuclear reactors, and study the extinction of other species. We can also step back from the world and witness it as a spectacle separate from ourselves, which we call â œnature.â

We are rooted in biology, and we can also think about it. Words and concepts are our specialty. We are the symbolic species par excellence. We can treat words as symbols for things that are not in our immediate vicinity. Our linguistic and symbolic capacities enable us to devise new relationships between unrelated concepts. Through language, we can exchange information, make plans, scheme, and strategize. Mastering language and symbols has led us to the top of the food chain. Lions and wolves have fangs and claws; we have cunning concepts that we can put to practice.

Language also allows us to pass on vast amounts of knowledge and experience to our children. The sophisticated technologies we have developed in recent decades grew out of the accumulated knowledge of our ancestors. Language has blasted us onto a steep learning curve.

These developments have been made possible by our brains. We have big brains. Relative to body size, the human brain is three times larger than might be expected in a primateâ ”and primates already have enlarged brains compared to other mammals. The top part of our brain, known as the cortex, has mushroomed during the evolution of hominids. Rita Carter describes this in her book *Mapping the Mind*: â œOne and a half million years ago the hominid brain underwent an explosive enlargement. So sudden was it that the bones of the skull were pushed outwards, creating the high, flat forehead and domed head that distinguish us from primates. The areas that expanded most are those concerned with thinking, planning, organizing and communicating. The development of language was almost certainly the springboard for the leap from hominid to human. It gave our ancestors lots to think about, and new brain tissue was needed. The frontal lobes of the brain duly expanded by some 40 per cent to create large areas of new gray matter: the neo-cortex. This spurt was most dramatic at the very front, in what are known as the pre-frontal lobes. These jut out from the front of the brain, and their development pushed the forehead and frontal dome of the head forward, reforming it to the shape of a modern skull.â

Our brains are organized into distinct areas. First, at the top of the spinal column, at the base of the skull, there are cells sensitive to smell and light. This corresponds to the fish brain. On top of this lies a clump of cells called the cerebellum, which coordinates movement. Together the two layers form the reptilian brain. Further areas lie on top of this, including the thalamus (involved in the primary sensory processing of vision, sound, and touch), the amygdala (involved in emotion), the hippocampus (involved in learning and memory), and the hypothalamus (involved in motivation and behavioral regulation). This corresponds to the mammalian brain, which also has an additional top layer of cells known as the cortex. Some mammals have more cortex than others. In humans, the cortex balloons out of all proportions.

The architecture of the human brain incarnates our hereditary connection to other vertebrates, in their order of evolutionary appearance: first fish, then reptile, then mammal. But the human brain differs from other animal brains in that it is equipped with specialized neuronal circuitry to deal with language. For decades, scientists believed that two specific parts on the left side of the human cortex, known as Brocaâ ™s area and Wernickeâ ™s area, function as â œlanguage centers.â But recent research based on brain imaging shows that language is handled by many different brain regions working in parallel. As Susan Greenfield writes in her book *Brain Story*: â œOne of the most startling discoveries from such research is that saying just a single word causes a unique pattern of activity to ripple through the cortex. The experience of the word â ˜screwdriver,â ™ for example, causes a part of the brain called the motor cortex to light up. The motor cortex is involved in controlling movement, so perhaps this word triggers memories of handling a screwdriver to become active. Obviously, language cannot be the preserve of just Brocaâ ™s and Wernickeâ ™s areasâ ”it involves an eruption of associations and memories that are different for every word.â

Humans have remarkably big brains compared to the rest of their bodies. Our children come into the world so top-heavy that they take months just to sit up. Their heads are so large that our species has by far the highest maternal death rate during birth. And young humans require long years of nurturance, education, and compassion for their brains to reach full potential. Humans also have by far the longest childhoods and adolescences, and human parents sustain compassion longer than parents from any other species.

Having a large number of neurons relative to body size certainly seems to enhance intelligence, as octopuses and humans demonstrate. But if intelligence is defined as the capacity to gauge the world and make correct decisions, there is some doubt that humans are as smart as some people fancy. Our current tendency to deplete the natural world with little consideration of the future shows that we do not yet have a grip on our predatory behavior. True, our species is very young. In comparison, octopuses have been around for several hundred million years, which has given them time to hone their skills. By comparison, we are just getting started.

Chapter 7

Plants as Brains

I had been looking into intelligence in nature for eighteen months when a friend called to draw my attention to a recent article in the journal *Nature.* It claimed that the investigation of plant intelligence is â œbecoming a serious scientific endeavorâ and that scientists are â œonly now beginning to expose the remarkable complexity of plant behavior.â These were the words of Anthony Trewavas, a professor of biology at the University of Edinburgh and a fellow of the Royal Society, the oldest scientific society in Great Britain. According to Trewavas, plants have intentions, make decisions, and compute complex aspects of their environment.

I looked into the research cited by Trewavas and found, to my surprise, that scientists were now saying that plants have senses and can detect a wide variety of external variables, such as light, water, temperature, chemicals, vibrations, gravity, and sounds. They can also react to these factors by changing the way they grow. Plants can forage and compete with one another for resources. When attacked by herbivores, some plants signal for help, releasing chemicals that attract their assailantsâ ™predators. Plants can detect distress signals let off by other plant species and take preventive measures. They can assimilate information and respond on the whole-plant level. And they use cell-to-cell communication based on molecular and electrical signals, some of which are remarkably similar to those used by our own neurons. When a plant is damaged, its cells send one another electrical signals just like our own pain messages.

A good part of this knowledge emerged during the 1990s thanks to the development of molecular genetics, which revealed the signals and receptors used by plant cells when they communicate and learn. Anthony Trewavas helped launch this field of investigation with his research on calcium and plant signaling. I contacted him and requested an interview, explaining my purpose. He accepted, and we set up a date.

I arrived in Edinburgh on a cold, stormy January night. As I walked along the streets, I braced myself against the wind and rain. It was my first trip to Scotland. It felt bleak, and I wondered whether I had come to the right place to find out about plant intelligence. I stayed in a hotel on the outskirts of town.

The next morning, the rain had stopped. I made my way over to the university and arrived well ahead of our planned meeting. I wandered around the corridors of the Institute of Cell and Molecular Biology, a nothing-special building designed in the 1960s, which now seemed run-down. Corridors in science departments tend to look alike from one country to the next, with drab walls covered with posters announcing conferences or explaining research.

I found Anthony Trewavas in his office on the fourth floor. A tall, balding man, he has piercing light-blue eyes and gray eyebrows. He invited me in and showed me a chair where I could sit down. His office was littered with stacks of journals such as *Science* and *Nature.* I glanced at the top file on the nearest pile of documents and saw that it was entitled â œIntelligence.â

By the time I turned on the tape recorder, Trewavas was already discussing the importance of plant intelligence, saying that scientists have long regarded plants as passive creatures, because they lack obvious movement. â œNow to my mind, that assumption is wrong because it requires an equating of movement with intelligence. Movement is an *expression* of intelligence. It is not intelligence itself. Now, the definitions of intelligence are difficultâ ¦â

He spoke fluidly, needing no prompting to continue his line of thought. He said he found it necessary to peel away the human aspects that come with the notion of intelligence. In his view, our intelligence did not suddenly appear when we became *Homo sapiens.* It evolved from other organisms. Hence the importance of defining intelligence in a way that does not apply exclusively to humans. Trewavas referred to the definition devised in 1974 by New Zealand philosopher and psychologist David Stenhouse, who described intelligence as â œadaptively variable behavior within the lifetime of the individual.â This can apply to many different organisms and means noninstinctive behavior that maximizes the individualâ ™s fitness.

Trewavasâ ™s desk stood against a bay window overlooking Edinburgh. He sat facing me, with his back to his desk. He looked straight at me as he spoke. His eyes had a piercing quality, but his tone was generous. He said he had spent years pondering the behavior of plants in the light of Stenhouseâ ™s definition. Though most plants do not move at a speed perceptible to the naked eye, they respond as individuals to signals from their environment and develop in adaptively variable ways. Even plants growing in pots inside houses turn their leaves to the light to optimize light collection and send their roots down in the soil and their shoots up into the air. And wild plants manage to compete with other plants for resources. Research now shows that growing shoots can sense neighboring plants. They can detect shifts in infrared light indicative of nearby greenery, predict the consequences of that presence, and take evasive action. Plants can alter the shape and direction of their stems to maintain an optimal position relative to sunlight. They can adjust their growth and development to maximize their fitness in a variable environment. According to Trewavas, this means they are intelligent, if one refers to Stenhouseâ ™s definition.

To illustrate his point, Trewavas described the behavior of the stilt palm. This tropical tree has a stem raised on prop roots and moves toward sunlight by growing new prop roots on the sunny side and letting those in the shade die off. By doing this over several months, the stilt palm actually changes places. It â œwalksâ around in this manner, fending off competitive neighbors and foraging for light, at a speed imperceptible to humans. Trewavas considers this a clear example of â œintentional behavior.â

Ground ivy is another plant with measurable foraging skills. This perennial weed creeps along the ground as a vine, and when it reaches a patch of optimal size and nutrient content, it puts down roots and generates leaves to catch the light. Scientists recently tested ground ivy in a controlled environment in which nutrients were distributed unevenly. The plant demonstrated that it senses resources by starting to grow roots much earlier in its development in the locations containing nutrients and by skipping over the poorer ground between rich patches. Trewavas finds it â œdifficult to avoid the conclusion of intention and intelligent choiceâ in the case of ground ivy.

Such examples cannot be dismissed as preprogrammed rote responses, he said. Rather, they demonstrate *plasticity.* He explained that an individual plant has an enormous capacity for changing its morphology, its branching structures, to accommodate the environment in which it finds itself. The transformation occurs very slowly from a human point of view, over a period of months, rather than milliseconds. â œBut the way in which it is conducted and the success with which it has occurred must indicate that a lot of computation goes into the decisions which are actually made, otherwise plants would not dominate this planet in the way that they actually do.â

Trewavas had obviously argued in favor of plant intelligence many times. I was willing to consider that Western cultures, and science in particular, had misjudged the vegetal world. But I wondered about the extent of plantsâ ™ capacities. I asked Trewavas if he thought plants *think* when they make decisions. He replied that he did not. In his opinion, they *compute* what is actually going on, then make appropriate responses in terms of what they perceive.

Having answered my question, he continued making the case for plant plasticity. Plants have to gather resources in their local environment while facing competition from their neighbors. As they are mainly fixed in one place, the most sensible way any plant can do this is to occupy the space around itself in an optimal way. A branching structure happens to be the simplest way in which this can be done, and this is the solution plants adopt, both below ground, as they send down roots into the soil to form exploitative tissues, and above ground, as they deploy their leaves to gather the maximum amount of light. To do all this, an individual plant must perceive a gravity vector and align itself correctly. And its actual shape and morphology are determined by the quantity and quality of light it perceives. For Trewavas, this is â œadaptively variable behavior within the lifetime of the individual, i.e., intelligence.â Furthermore, individual plants do not choose their environment, as seeds land and germinate where they can. Plants have to grow in a great variety of environments and adjust their structures to optimize their ability to exploit what they find.

Trewavasâ ™s favorite example of vegetal intelligence and plasticity is a parasitic plant called dodder. It moves around by wrapping itself around other plants and correctly estimating their nutritional quality. Within an hour, dodder decides whether to exploit a host or to move on. If it stays, it takes several days before beginning to benefit from its hostâ ™s nutrients. But dodder anticipates how fruitful its host will be by growing more or less coils. Growing more coils allows greater exploitation; but if the host is poor in nutrients, this wastes precious energy, because dodder lacks leaves and relies on its hosts for water and food. So it has to make correct decisions or face death. Botanist Colleen Kelly, working in the early 1990s, found that dodder correctly assesses when to eat and when to move on, and that its foraging strategies have the same efficacy as those of animal foragers. And it computes the right choice between close alternatives without the benefit of a brain.

Trewavas described plants as having intention. But I had in mind Jacques Monodâ ™s statement that attributing purpose or goals to nature contradicts the central method of science. According to Monod, studying nature scientifically means ignoring the possibility of intention. I reminded Trewavas of this postulate and added that he seemed to have crossed the line.

He scoffed: â œWell, I donâ ™t know how many people actually believe Jacques Monod in that regard. That was an idea that did not really apply to humans, did it? It seemed to devitalize life in my own view. It seemed to indicate that life was solely governed by chance. And animals have foresight. And so do we. And to me, plasticity must be foresight, because itâ ™s the ability to adjust to the particular environmental conditions which you find. If you didnâ ™t have that ability, then you would not be able to accommodate optimally to that. Possessing plasticity is in a sense foresight of the possible conditions in which the plant will actually find itself.â

How, then, does a plant make up its mind? I asked. Trewavas replied that he had pondered this question for many years. In 1990, he and his colleagues had a breakthrough. They were studying how plants perceive signals and transmit information internally. Using genetic manipulation, the scientists inserted into tobacco plants a protein that makes them glow when calcium levels rise inside their cells. They suspected changes in cellular calcium concentration to be a major means by which plants perceive external events. To their amazement, they found the tobacco plants responded immediately to touch. Though tobacco is not known to be touch-sensitive, one gentle stroke caused the modified plants to glow with the light produced by the elevation of calcium inside their cells. Trewavas was dazzled by the speed of the response: â œIt was as fast as we could measure. Whereas I have been telling you that plants only respond in terms of weeks and months, in this case, they were responding in milliseconds to a signal which we knew would later have a morphological effect. If you keep touching a plant, it slows down its growth and it gets thicker.â

Trewavas knew that human neurons also use internal calcium elevation when they relay information. Once he saw the speed of the plantsâ ™ reaction to touch, he started thinking about intelligence. Plants may not have neurons, but their cells use a similar signaling system, he told himself, so they may have the capacity to compute and make decisions.

As I listened to him, I realized that he had firsthand experience of the changes that had swept across contemporary biology in recent decades. He had opened himself to the idea of intelligence in nature. This was a courageous step for a Western scientist. I knew indigenous people in the Amazon who consider it a matter of course that plants have intelligence. But in Western cultures, those who attribute intelligence to plants have long been the objects of ridicule. Until now, scientists, and in particular botanists, had avoided using the words *plant intelligence.* I wanted to know more about how his thinking had changed and pressed him for details.

Gesturing at the documents piled around his office, he said he had read up on a number of different subjects over decades. He described his work method in some detail. â œThe family used to complain that I would sit in a chair vacantly thinking. I found it very necessary to do. The ideas donâ ™t just come by reading. You have to go away, lie down, sit down, walk about, and let things turn over in your mind. And what I find particularly enjoyable is a problem Iâ ™m trying to solve in my own mind. Is there something I can connect together? And I find itâ ™s only by long periods of doing nothing but think that suddenly facts start coming into your mind. And they come together in an interesting combination which enables you to see the possibilities for what plants can actually do.â He said the notion of plant intelligence had come to him in this fashion. Intelligence in general was a subject that had interested him for years. So when he saw the connection between plants and calcium, it inevitably led him to think about intelligence.

Trewavasâ ™s intuition about calciumâ ™s role in learning in both animals and plants was confirmed by subsequent research. Scientists recently discovered that when an animal learns to avoid a threat, charged atoms of calcium and specific molecules including enzymes are unleashed inside its neurons. They set about modifying the molecular structure of the channels that span the neuronsâ ™ outer membranes and control the import and export of charged atoms and molecules. If the threat to the animal persists, its neurons go on to produce proteins that build new connections, or synapses, between neurons. Along with changes in the strength of existing connections, these new synapses give rise to memory, and allow the animal to remember the threat and avoid it.

An analogous process occurs in plants. When a plant is threatened, by lack of water, for example, exactly the same atoms and molecules are unleashed inside its cells. And they set off the same reactions, first modifying the same import-export channels, then stimulating the production of proteins if the threat persists. Eventually, the plant modifies its cells and their behavior so that its leaves get smaller, its shoots cease to grow, and its roots extend. These responses minimize further stress and injury to the plant. They also take into account external factors such as nutrients and temperature, as well as the plantâ ™s age and previous history.

Science now indicates that plants, like animals and humans, can learn about the world around them and use cellular mechanisms similar to those we rely on. Plants learn, remember, and decide, without brains.

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WE HAD BEEN TALKING for an hour and a half. Trewavas invited me to accompany him to the rooftop cafeteria for a cup of coffee. We wove our way through a labyrinth of corridors and staircases, and through packs of students coming in and out of lectures. The cafeteria was quiet and luminous. It offered a spectacular view of Edinburgh and its surrounding hillsides on a crisp winter day. Trewavas was being generous with his time and knowledge, and was certainly one of the easiest people to interview I had ever met. There had been moments during our conversation when I found it difficult to get a word in edgewise.

Drinking coffee together seemed to be a good time to get more personal. I decided to ask him whether his own behavior toward other species had changed in light of his scientific research. After all, his work showed that we have more in common with plants than most people suspect. He replied that his behavior had not changed much, as he had always respected other species, and had always enjoyed the company of plants and animals. This led him to discuss cruelty toward animals, a much-debated subject in Great Britain. Upon reflection, he realized that his behavior had changed on one count, namely that he had given up fishing. He had come to feel sympathy for the fish, because he could see that a fish on the line is frightened out of its life. Now he considers fishing to be relatively cruel. From his point of view, it is self-evident that animals feel pain. â œYou throw a fish out of water, and itâ ™s flapping around; well, the reason itâ ™s flapping is because itâ ™s trying to get air. And I suppose I can anthropomorphize that situation and see that I would be doing exactly the same damn thing if I was put into water, trying to get air in my lungs, not water. But I like eating fish. I just prefer someone else to catch it. We have to respect the system in which we live, because it will not survive if we donâ ™t respect it. And thatâ ™s all there is to it, and I think that is vaguely self-evident. On the other hand, you canâ ™t go overboard about it. We are the important organisms. Itâ ™s us discussing the environment and other animals, and not the other way around.â

â œTo our knowledge,â I interjectedâ ”meaning that we could not be sure that other species were not discussing us. But this did not stop his train of thought. He said that we had to learn to live with other species, and he referred to the work of a fellow member of the Royal Society who had carried out hormonal studies on deer that had been hunted; it showed beyond doubt that these animals were extremely frightened. Trewavas now views hunting animals for pleasure as a lack of respect for life. It was simply untrue, he said, that foxes enjoy a good hunt before being torn to pieces. I found nothing to argue with there.

We returned to his office to wrap up the interview. I asked him about future research on plant intelligence. What remained to be done, he said, was to work out how the whole plant assesses its circumstances, makes a decision, and changes what it is doing in response to the environment it perceives. â œThat requires a lot of communication between the various parts of a plant. It has become an extremely complex area, remarkably complicated. And I can see that we have underestimated this in the past to an enormous extent. People are going to have to keep working on this and try to appreciate that what they are looking at, in fact, is an organism that does exhibit intelligent behavior, and not in ways they normally perceive intelligence.â

It was still not clear to me how and where computation occurs in a plant. According to a view Trewavas had expressed in writing, â œplant communication is likely to be as complex as within a brain.â I told him that when I read that sentence, I pictured the whole plant as a kind of brain.

â œYes, thatâ ™s interesting,â he said. Then he began comparing the chemical signals used by neurons to those used by plants cells. Some are the same, but others are different. Brain signals tend to be small molecules, whereas plant signals tend to be large and complicated, such as proteins and RNA transcripts. This had only become clear in the last five years, he said. Prior to that, â œno one would really believe that proteins would be swimming around a plant providing information.â And large molecules can handle large amounts of information, which means there is room for enormous complexity in plant communication. â œBut you are quite right when you ask about computation: Where does it actually exist? I just donâ ™t know. And the answer is almost certainly: Itâ ™s in the whole organism.â

Plants do not have brains, so much as act like them.

Later that day, I wandered through the streets of Edinburgh. The clouds had cleared, and the winter sun lay low on the horizon. The city and the volcanic cliffs overlooking it were bathed in pale light. I went over the morningâ ™s conversation with Anthony Trewavas. We humans have different timescales from those in plants. Consequently, we do not see plants move and assume they are stupid. But this is an incorrect assumption caused by our animal nature. We do not see them move because we operate in seconds, rather than weeks and months.

I stopped on the sidewalk of the cobblestone street leading up to Edinburgh Castle and remained immobile. I breathed and watched people walk past. I tried shifting to a plantâ ™s timescale, but my thoughts kept racing at animal speed. An image popped into mind of Trewavas sitting in an armchair, not moving, thinking about plants. He was acting like a plant to understand plants, and attributing intelligence to them. Like a shaman, he identified with nature in the name of knowledge. His eyes were shining.

Chapter 8

SMART SLIME

Seeing that plants can make decisions led me to look into other cases of intelligent behavior by brainless organisms. I focused on simple species in search of the basic conditions of intelligence.

Amoebas attracted my attention. Their name comes from the Greek *amoibe,* meaning change. These microscopic single-celled creatures mainly consist of a blob of protoplasm surrounded by a porous, flexible membrane. Amoebas move around by transforming themselves. They change the shape of their bodies by shifting their jellylike contents and stretching their membranes to form extensions known as pseudopods, or â œfalse feet.â Amoebas are shape shifters, transformers.

Some amoebas have the capacity to merge with one another to form a single giant cell, with thousands or millions of nuclei. Known as true slime molds, these peculiar unicellular organisms can grow as big as a human hand. And if one of them is diced up, the pieces will put themselves back together. Creeping around slowly and engulfing food along the way, true slime molds act like giant amoebas. There are approximately one thousand species of true slime molds, and they occur around the world, in particular in temperate forests. In their visible, aggregate state, they look like glittering blobs of mucus, or spilled jelly. They can be white, red, orange, or yellow. Typically, a true slime mold changes shape as it crawls over damp wood, leaves, or soil, ingesting bacteria, molds, and fungi. Its entire body is covered by a layer of slime, which it secretes continually and leaves behind as it crawls forward. Though true slime molds are composed of only one large cell, and therefore lack nervous systems and eyes, they can move, navigate, and avoid obstacles. They can also sense food at a distance, and head unerringly toward it.

True slime molds defy categories. They move around to feed themselves, like animals. But they give rise to fruiting bodies containing spores, like fungi. Once their spores disperse to new habitats, they â œgerminateâ into microscopic amoebas. The true slime moldâ ™s life cycle is completed when these tiny amoebas merge into a single, giant cell. True slime molds spend their lives going between two kingdoms, fungi and animal, and between two scales, microscopic and macroscopic.

Scientists recently discovered that true slime mold, *Physarum polycephalum,* can consistently solve a maze. They found that when separate pieces of this bloblike organism are placed in a maze, they spread out and form a single cell, which fills all the available space. But when food is placed at the start and end points of the maze, the slime mold withdraws from the dead-end corridors and shrinks its body to a tube spanning the shortest path between food sources. The single-celled slime solves the maze in this way each time it is tested. â œThis remarkable process of cellular computation implies that cellular materials can show a primitive intelligence,â the scientists concluded. The Japanese biologist who initiated the experiment, Toshiyuki Nakagaki, declared: â œI must recognize that this organism is so clever and cunning.â A common view is that intelligence requires a brain. And brains are made of cells. But in this case, a single cell behaves as if it had a brain.

If a single cell of yellowy slime can solve a maze, does this not confirm that the entire edifice of life contains intelligence? I read other publications by Toshiyuki Nakagaki with titles such as â œAmoeboid Organisms May Be More Clever Than We Had Thoughtâ and conclusions such as â œI had better change my stupid opinion that a unicellular organism is stupid.â I liked what I read so much that I contacted Nakagaki and requested an interview. He replied positively, and I began planning a trip to Japan, a country I had never visited, and where few people speak European languages. I invited along my companion, Beatrice, who has traveled widely in Asia and who is a speech therapist.

In late July, we caught an all-night flight from Switzerland to Tokyo, then flew north to Sapporo, where Nakagaki works as an associate professor at Hokkaido University. We arrived in the middle of the afternoon local time, checked into a hotel, had some coffee, then walked around town. The weather was sunny and crisp. Sapporo is modern and easy to get around, with tree-lined avenues. It reminded me of Vancouver. We ended up in a Japanese-style Italian restaurant called Africa and drank too much wine.

The following morning, we overslept and barely managed to make our appointment in the hotel lobby. Fortunately, Nakagaki was running late. It was raining outside. He showed up perspiring and carrying an umbrella. He was wearing wire-rimmed glasses, which suited his oval face. His short black hair was slightly graying on the sides. He seemed to be in his early forties. He dressed in an elegant and relaxed style: a checked shirt, green pants, socks, and thongs. Western clothes, Japanese footwear.

We walked under umbrellas as he led us across the campus. There were tall trees and spacious lawns between the buildings. Nakagaki explained that an American had founded the University of Hokkaido in the nineteenth century. At one point, he turned to me and said, â œActually, you are not a scientist.â I was surprised by his directness. No one had said this to me before; in fact, people often assume the contrary. But I agreed with him.

We reached the Research Institute for Electronic Science, where Nakagaki has his office and laboratory. On entering the building, he asked us to take off our shoes and put on slippers, following Japanese custom. As we walked up the stairs to the third floor, he gestured at the walls and said, â œThis is a cheap building.â

Nakagakiâ ™s office appeared bare. It contained a desk, three basic chairs, simple white shelves filled with books, and a writing board. There was a large computer on his desk with a screen showing an e-mail in Japanese script. It caught my attention, and I noticed that the keyboard was marked with European characters. I asked how one wrote in Japanese on such a computer. He explained that Japanese uses three different scripts, including an ideographic script of Chinese origin, an alphabet of syllables to make up for the differences between Chinese and Japanese grammars, and a second alphabet of syllables for representing words imported from European languages. He went to the writing board and started showing us the different scripts. Then he returned to the computer and showed how one could shift the keyboard into a mode that allowed one to compose all three Japanese scripts. I felt relieved that Nakagaki spoke English.

He asked me to explain my interest in his work. I told him that studying the knowledge of indigenous Amazonians had led me to investigate intelligence in nature. He listened, then commented on the problem Western people have with applying the concept of â œintelligenceâ to nature. He said it was possibly due to the influence of Christianity. I had not turned on the tape recorder yet. I asked him to pause briefly while I did so. Then he resumed and described the conditions in which he and two colleaguesâ ”one Japanese and one Hungarianâ ”had published their experimental demonstration that a true slime mold can solve a maze. Nakagaki and his Japanese colleague did not hesitate to refer to â œintelligenceâ in their conclusion. But the Hungarian co-author proposed to delete the term. The two Japanese scientists prevailed, and the journal *Nature* duly published their paper containing the word *intelligence.* Much media attention ensued, both in Japan and abroad. Nakagaki said, â œI have, in the course of my press interviews about this subject, found myself discussing with foreign reporters just what intelligence is. Whereas Japanese reporters were most deeply concerned with the details of just how such an organism was able to solve a maze, those from overseas tended to focus on whether or not the phenomenon represented intelligence.â

He attributed this difference to religion. â œI got the feeling that some Western people, possibly because of the influence of Christianity, may feel somewhat uncomfortable when faced with the possibility of intelligence other than human.â In Japan, he said, people do not hesitate to refer to nature, and even to materials, as intelligent. â œIn Japanese culture, we have a religion of Shinto, which is a sort of animism. So we are likely to accept that everything has spirit, or something like that. This is quite a natural thing for me,â he said, laughing.

He got out of his swivel chair, went to the writing board, and marked the Japanese term for intelligence: *chi-sei,* in which *chi* means to know, to recognize, and *sei* means property, or character, or feature. Like knowingness, or recognizing-ness. He pronounced it CHEE-SAY.

â œ*Chi-sei* is the term used to translate the English term *intelligence*. But I feel there is some difference between these two words, in their background meaning.â He wrote the word intelligence on the board: â œI feel that behind this term, there is Western Christian culture, in which intelligence is a gift from the God to humans only.â He laughed, then went to his desk and pulled out an article entitled â œSmart Behavior of True Slime Mold in a Labyrinth.â He handed it to me, saying it contained his view on the definition of intelligence.

I had already read this article by Nakagaki, in which he reflects on what the true slime mold actually does in the maze. By adjusting its body shape to occupy the shortest route between two food sources, it optimizes its intake of nutrients and its chances of survival. â œIf the survival mechanism works well even in complicated and difficult situations, then the behavior seems to be smart,â Nakagaki writes. â œAll biological systems must be rather smart. It is not yet known how smart the microorganisms are. In fact, (true slime mold) *Physarum*â ™s smartness may be more involved than simply maze solving because life in the wild is more complicated and difficult.â

When I first read this article, I wondered what difference Nakagaki made between *intelligence* and *smartness*. I put the question to him. â œWhen I use the term *smart,* Western people agree,â he replied, laughing. â œRecently I have only used the term *smartness*.â

I asked whether smartness corresponds to the Japanese term *chi-sei.* He said, â œJust a moment pleaseâ and went back to the drawing board. He seemed at ease standing up, writing out words, and drawing connections between them. He explained that in Japan, people call chemical materials that have functions *intelligent materials.* But in English, the corresponding term is *smart materials.* â œI didnâ ™t know this correspondence,â he said. â œI thought Western people used *intelligent materials.*â He associated intelligence with â œspirit, or mind, or awareness, or something like that,â while smartness is â œrather neutral, or physical, or well designed.â He listed these terms on the board.

I said I understood the term *smart* to mean flexible and quick when referring to materials.

â œAh, okay, so this word is more appropriate for our study,â he said. â œFlexibility and adaptability.â He wrote both terms under the smartness list.

This prompted me to mention the definition of intelligence used by Anthony Trewavas when referring to plants: â œadaptively variable behavior during the lifetime of the individual.â

â œYes, yes, yes,â he said. â œAll kinds of organisms have such abilities, adaptability and flexibility. This is true, I believe.â He contrasted these abilities to *awareness* and *mind* and went on to discuss information processing in biological systems. He wrote the word *unconsciousness* on the board and said that most information processing in humans occurs at the unconscious level. â œSo awareness is the small tip of a large mountain. In this sense, all kinds of organisms have a sort of unconscious level of information processing. This ability is very high, higher than we expect.â

Nakagaki pulled out a round, plastic dish and handed it to me. It contained the original 3-by-3-centimeter maze in which he and his colleagues had tested the slime mold. It consisted of a negative of the maze cut from a plastic film and superimposed on an agar plate. As true slime molds dislike dry surfaces, they tend to crawl only on the wet, gelatinous agar plate, which the plastic film does not cover.

Then he turned to his computer and showed us some video images of the experiment. First one sees Nakagaki cutting about thirty small pieces from the growing tip of a living slime mold and placing them throughout the maze. As true slime molds move at a speed of about half an inch an hour, it takes a time-lapse camera to reveal their movements. A two-minute sequence concentrating several hours of action shows the bits of slime spreading themselves along the mazeâ ™s corridors and blending into one another. They become a single organism, one giant cell covering all available space within the maze. Nakagaki then places the slime moldâ ™s favorite food, oatmeal, at the start and end points of the maze. Waves start rippling across the yellowish body of the slime mold, emanating from around the oatmeal and splashing down the mazeâ ™s corridors. The flat mass of yellow jelly that makes up the slime moldâ ™s body begins to develop veins that run through the maze. The slime mold ends up withdrawing from blind alleys, avoiding detours, and reducing itself down to a single yellow vein connecting the two food sources by the most direct route.

After seeing these images, I asked Nakagaki if he could show us a living slime mold. He accompanied us out of his office and across the corridor into the storage room for unicellular organisms. The room itself was painted in drab yellow and contained several refrigerators. He opened one and brought out a foot-long plastic container half filled with a bright yellow slime mold. On close inspection, the giant unicellular creature had a solid texture, like mashed potatoes. Nakagaki explained that when a true slime mold lacks water, it goes into a dormant phase during which it becomes dry and can be stored almost indefinitely.

I asked how the idea of putting a true slime mold into a maze first came to him. He said that several years previously, one of his jobs was to feed the laboratoryâ ™s slime molds. He usually gave them oat flakes. One day he noticed that if he sprinkled the oat flakes randomly on top of a slime mold, it would form tubes connecting the food sources, and that the tubes were connected to one another in a such a way that the organism derived the maximum amount of nutrients in the minimum amount of time. As Nakagaki has training in mathematics, he began trying â œto clarify the smartness of that tube network.â He said the point of the maze was to test the expression of that smartness.

We headed back to his office, and he explained that the single-celled slime has the capacity to turn itself into an efficient network of tubes. This is impressive considering that humans have difficulty deducing the shortest connections among just a few locations. He sketched a few examples of tube networks set up by true slime molds. The writing board was starting to look like an evolving road map. He erased old parts and drew over them.

Nakagaki said that a true slime mold turns into an efficient tubing network by contracting and relaxing its body in waves. By varying the rhythm of the contractions, it can move its gelatinous contents either inward or outward. For example, when food is sprinkled on a slime mold, its contractions change drastically. These contraction patterns are self-organized, as there are no leaders or conductors in the protoplasm; rather, parts of the homogeneous slime interact in a synchronized way. Just how this kind of self-organization works is a serious question for mathematics and theoretical physics, according to Nakagaki. â œSo in this organism, there is no nervous system, no brain, but it has the ability to solve difficult mathematical problems. But the way of computation of this organism is quite unknown,â he said.

The rhythmic contractions that ripple across the slime mold and allow it to move are regulated by a complex mechanism that has yet to be elucidated. So far, researchers have determined that different substances participate in the regulation of these contractions, including charged atoms of calcium, which oscillate. These biochemical oscillators may give rise to waves that propagate through the slime moldâ ™s body and that seem to lead to the development of tubes. But the details remain obscure. Nakagaki thinks the way forward in understanding how a slime mold does what it does is to proceed with mathematical modeling of its behavior, and in particular of its contractions. Understanding what happens in the contraction patterns from a mathematical point of view would allow one to understand how it self-organizes its movements. This, he said, was the main subject of his current research.

I asked how his work had been received by the international scientific community. He said that he goes to international conferences on applied mathematics and physics, and that researchers in these fields have welcomed his work. But he had hardly received any responses from biologists. I found this surprising and asked why he thought it was so. â œRecent biologists work on molecular biology,â he said. â œTo such people, it does not matter how the biological system works. They are, in principle, only chemists.â He laughed. â œBut biologists in the field investigating the behavior of animals like my results.â

My impression was that an increasing number of scientists were opening up to the idea of intelligence in nature. I asked Nakagaki whether he agreed. He replied that after publishing his research on maze solving by the slime mold, he had become more careful in his use of the term *intelligence*. Its definition seemed to change from one person to the next, and some critics argued that the slime moldâ ™s behavior could not be considered intelligent because they did not believe it solved the maze by conscious decision.

I asked how those critics could be sure that a slime mold is not conscious.

â œI donâ ™t know,â he replied. â œBut, Iâ ™ll say it again, consciousness is the small tip of a large mountain.â He considered *consciousness* to be a useful term to refer to self-awareness, as when humans observe themselves observing themselves.

I doubted that introducing concepts of consciousness and self would cast much light on intelligence, if only because the workings of consciousness and the nature of self remain obscure. Nevertheless, Nakagakiâ ™s research showed that the slime mold computes. And many consider computation to be among humanityâ ™s finest intellectual achievements. I asked him about this.

â œThe slime mold computes,â he replied, â œbut this process corresponds to the unconscious level, I think.â He stood up and wrote *unconscious level* on the board. In his view, most internal information processing takes place on this level, even among human beings. â œI doubt anyone could explain how it is their body maintains balance when they ride a bicycle. While we are riding, our body just naturally performs the calculations required to solve the equation. It would be quite difficult for us to clearly define these on the conscious level, and were one able to do so and publish the method employed, it would undoubtedly be an important contribution to the scientific literature.â For Nakagaki, all living organisms have unconscious information-processing mechanisms. Whether this constitutes *intelligence* is a matter of debate. His research aims at clarifying these mechanisms, he said, if possible at a material level, in order to find out whether or not single-celled creatures possess intelligence. In this effort, he considers the slime mold to be an ideal subject.

Having spent the afternoon talking, we went out to dinner. Nakagaki invited along his wife, Yuka, and their three-year-old son, Gen-ichiro. We went to a restaurant specializing in traditional Japanese cooking and sat together around a low table in a room partitioned off from others by bamboo walls. Yuka had worked as a travel agent for ten years. She spoke with enthusiasm, and in fluent English, about South Korea, one of her favorite countries to visit. Gen-ichiro played quietly with his motherâ ™s cell phone. Though we drank a number of glasses of sake, I still had some questions. In particular, I wanted to know what Nakagaki thought about the importance of studying intelligence in nature. He replied that it is â œone of the most important questions in science.â

I agreed but said that, until recently, most scientists had held the opinion that nature lacks intelligence.

â œSo, this opinion is wrong. This is obvious,â he said. â œMost scientists are surely ill informed on this question. They only think about their own subject. Apart from their own subject, they are ill informed.â

He looked straight at me from across the table and added, â œYou think about intelligence in nature, and you investigate many cases of research describing intelligence in nature. So you know more about this intelligence than I do. So you are the specialist on the problem of intelligence in nature. Whether you are a scientist or not does not matter. Since the times of Greek philosophy, we have basic questions on the mind and intelligence. Archimedes and Pythagoras thought about these serious problems. Descartes also thought about them. In this time, only a few people think about this serious problem. We do not have to share the opinions of most scientists.â

After the discussion with Nakagaki, I thought about the concept of *chi-sei*. He said that Japanese people did not question applying this term to the maze-solving slime mold. This was perhaps a concept I needed. *Intelligence* had been defined in too many different ways and had become a loaded word. And *smartness* commonly means cleanliness, tidiness, and elegance, which weakened its pertinence to my investigation. When a true slime mold solves a maze, it demonstrates a capacity to recognize its situation, to know. And if a true slime mold has *chi-sei,* what living entity does not?

Chapter 9

Japanese Butterfly Machines

After hiking up a smoking volcano near Sapporo, Beatrice and I headed south to Kyoto, the historical center of Japanese culture. Kyoto is hot and muggy in the summer. It also has two thousand temples. We spent several days seeing the sights. We walked along the Path of Philosophy, which follows a canal lined with cherry trees. We visited the Golden Temple Kinkaku-ji in the rain. We strolled through manicured gardens with moss carpets and ponds filled with sacred carp. One sign with an English translation posted at the entrance of a temple explained that Zen gardens are â œcompressed nature.â Another sign above a small exhibit of moss samples stated: â œVery Important Moss (like VIP).â Paying attention to details in nature appeared to be a Japanese talent.

We caught a train from Kyoto to Tokyo and settled into a small hotel downtown. The sheer size of Tokyo takes getting used to. No sooner had we found our bearings than the first typhoon of the season blew in. Dark clouds filled the sky, and gales of wind blasted down the avenues. Almost horizontal sheets of rain poured down. People in the streets braced themselves and walked with their umbrellas directed against the winds.

The next day, the typhoon was still raging, and we traveled to Yokohama, the countryâ ™s second biggest city, which now forms an uninterrupted megalopolis with Tokyo. I had an appointment at the University of Yokohama City with Kentaro Arikawa, a professor who has been studying butterfly neurology for twenty-five years. Arikawa is the scientist who discovered that butterflies have color vision, and that their tiny brains contain sophisticated visual systems. He also discovered that butterflies have eyes on their genitals.

The Tokyo subway system is mainly signposted in Japanese, and labyrinthine. We ended up finding the over-ground line to Yokohama, which we rode for an hour through an unending urban landscape. The train shook from the storm raging all around us. Once we reached our final destination, I called Kentaro Arikawa from a public phone outside the station, as he had instructed me to. A few minutes later, he appeared driving a gray car and flashed his lights in our direction. We were easy to recognize as the only *gaijin,* or foreigners, in the vicinity. We rushed through the downpour and got into his car as quickly as possible. We shook hands, then Arikawa drove off saying that we did not have far to go.

I sat in the front seat and wiped the rain from my face. Arikawa was a lanky man with short black hair, wire-rimmed glasses, and a kind, gentle face. He was in his mid-forties. He wore a a short-sleeved shirt, dark pants, leather shoes, and a big watch that looked suited to underwater diving. After a short drive we reached the campus of Yokohama City University and pulled up in front of the Graduate School of Integrated Science, where Arikawa teaches and conducts research. As we dashed from the car to the main entrance, I asked him what butterflies do during typhoons. â œThey hide in holes in trees,â he said, â œor under leaves.â

This time we did not take off our shoes. We walked over to the elevator, went up to the fifth floor, and proceeded into Arikawaâ ™s office. He invited us to sit around a comfortable table and offered to make some tea. I explained my interest in his work by describing my investigation and saying I saw clear indications of intelligence on nearly all levels of nature, including in plants.

â œI donâ ™t know much about plants,â he said, â œbut our intelligence must have originated from animals which were our ancestors. So intelligence, the mechanism of making decisions, must exist in present-day animals. And as you say, it is widespread, even in butterflies.â He described the work he and his colleagues are conducting, looking at the capacity of butterflies to see colors: â œWe have already found an enormous complexity in the eye. And of course we are looking at conscious behavior, and we showed that they can clearly see colors and have color constancy.â

Arikawa explained color constancy by giving the example of a human observer who sees a red apple as red in both sunshine and regular room light, though the spectral contents of sun and room light are very different; in such a case, the subjective experience of red remains the same, because the observerâ ™s brain adjusts its perception of the wavelengths reaching the eyes. This is color constancy. It turns out that the microbrains of butterflies are also capable of this feat.

Arikawa pulled out a black page showing a series of colored patches and began explaining how he and several colleagues had demonstrated that Japanese yellow swallowtail butterflies have color vision and color constancy. The scientists trained the butterflies to feed on sugared water placed on a patch of a particular color in a cage set in the laboratory. Then they presented the butterflies with the training color randomly positioned within an array of patches and devoid of sugared water. The butterflies selected the training color reliably among different colors, including a variety of shades of gray. They also selected it under different-colored lights, showing color constancy. Butterflies must be able to see colors in order to recognize suitable flowers for feeding in the field. They use color information to collect food. And because food must be food, under direct sunshine or in the woods or anywhere else, color constancy is important to butterflies.

Arikawa and his colleagues also demonstrated in the course of their studies that the retina of the swallowtail butterfly has at least five different types of spectral receptor: ultraviolet, violet, blue, green, and red. They recently found a sixth receptor, which is broadband, and probably works as a general luminosity detector. In comparison, humans have only three types of spectral receptors: red, green, and blue. Arikawa and his colleagues concluded: â œThe extremely richly endowed visual system of butterflies evidently provides these animals with a versatile information-processing apparatus.â

Astonishingly, the tiny brain of a butterfly is equipped with a system of color vision that is superior in some respects to our own.

Ultraviolet photoreceptors serve several purposes. They enable butterflies to see flowers that have pigmented ultraviolet spots indicative of nectar and pollen within. They also allow male butterflies to detect the distinctive ultraviolet stripes on the hind wings of female butterflies, which facilitates courtship and mating. Sometimes nature uses signs that human eyes cannot detect.

Butterfly visual systems develop during metamorphosis, when young butterflies are still full-grown caterpillars undergoing self-transformation in the pupa. While caterpillars have six simple eyes on each side of the head, butterflies develop an additional pair of large, compound eyes. The simple eyes of caterpillars have only three kinds of photoreceptors, while the compound eyes of butterflies have twice as many. Butterflies are transformers. They do not sprout just wings in the pupa but brand-new eyes as well.

I found Arikawaâ ™s work fascinating, but I wondered what could drive a person to spend several decades focusing on color vision in butterflies. I asked him about it. He replied, â œI am actually a color-blind person, and I have been interested in color vision processing in general. I wanted to know how the processing of color goes on in the brain and in the eyes. And I have really liked butterflies ever since my childhood. I was raised as an insect guy. My father gave me nice insect nets and took me to places where I collected butterflies and beetles.â

Arikawa said that when he was young, he had a science book for children which stated that insects in general do not see red. This was the received scientific opinion at the time. But Arikawa knew better because he had closely observed the behavior of butterflies in his parentsâ ™ garden in Tokyo: â œMy mother loved flowers, and she had lots of flowers in the garden. We had huge tiger lilies and hibiscus. And I knew that these butterflies really prefer red flowers over yellow and blue. It sounded strange to me that insects, including butterflies, cannot see red. So that is really the first point at which I became interested in the color vision system of butterflies.â

Arikawa has studied butterflies for his entire professional life. He made his first contribution to science as a graduate student, back in 1979, when he discovered that butterflies have light-sensitive neurons next to their genitals. He found that they use these â œeyes,â or photoreceptors, for correct coupling between males and females, and that females also use them to confirm that they are correctly laying eggs.

Once Arikawa settled into his academic teaching position, he went on to prove that butterflies have color vision including red sensitivity. I asked, â œNow that you have been studying their brains and visual systems for so long, do you think they think?â

â œI hope so,â he replied.

â œWhy do you hope so?â

He laughed. After a long pause, he said slowly: â œItâ ™s probably a problem of the definition of the word *think.* They have to make decisions, in any case.â He went on to give some examples. Butterflies have to decide which flowers to visit, taking into consideration how hungry they are and which sort of food they want. Depending on circumstances, they may want something more watery than sticky nectar. He said butterfly decision making was not simple. He paused again. We sat in silence for a while. Then he said, â œI believe that there must be some primitive form of mind in these animals, or the ability to think in things. I donâ ™t think that a simple chain of reflexes is sufficient to explain the whole thing.â

During the silence, I thought about Arikawa thinking about butterfly thinking. This reminded me of the story by Chuang-Tzu, the presumed founder of philosophical Taoism, who dreamed he was a butterfly, and then no longer knew, when he awoke, whether he was Chuang-Tzu who had dreamed he was a butterfly, or a butterfly dreaming he was Chuang-Tzu. I asked Arikawa if anybody had studied butterfly dreaming, or brain states associated with dreams known as rapid eye movement (REM). He said that such studies could not be carried out because butterfly eyes do not move, as they are fixed to the head capsule. â œEye movement means head movement. There could be some head movement when they are sleeping, but we actually do not have a clear definition of their sleep yet. At night, they are quiet, they do not move, and they hang under leaves, so they look like they are sleeping, but I donâ ™t know.â

Arikawa was quick to point to the limits of his knowledge. He also used words carefully, even though English is not his mother tongue. His approach to the practice of science had a well-rounded feel to it. This seemed appropriate as we were sitting in the Graduate School for Integrated Science, a university department where students learn a combination of physics, chemistry, biology, and mathematics, in order to develop the ability to produce interdisciplinary work.

True interdisciplinary approaches in science are rare. There was something about the work of Japanese scientists that seemed mature in this regard. I asked Arikawa what made Japanese science special. At first, he answered with modesty, denying that Japan has any more qualities than Western countries when it comes to interdisciplinary approaches. But I knew that showing modesty is traditionally considered a virtue in Japan, even when one is more experienced and knowledgeable than others. According to one Japanese saying, â œA clever hawk conceals its talons,â meaning to say that truly competent people do not make a show of their abilities.

I insisted on the wizardry of much Japanese technology and said it showed that something special was going on in Japanese laboratories. He laughed and said, â œI know too much about this country. So itâ ™s very difficult for me to say what is particularly Japanese in comparison to other nations. But one thing I can say is that we do not hesitate to break old things. The main part of Japan was totally destroyed during the last war. We discarded things and imported many new things.â He said he sometimes felt sad for the Japanese when he went to Europe and saw how people still live in very old buildings. He also said that the fact that most Japanese people do not live in old buildings gave them the advantage of â œnot being trapped in old cultures.â

In deliberate reference to butterflies, I asked whether it was fair to say that Japanese people like *metamorphosis.* He laughed and said, â œIn some sense, yes. We were forced to metamorphose, by the war, and also by the natural environment, because we have plenty of volcanoes, and we have typhoons and earthquakes which destroy everything. So our old buildings can simply not survive because of nature.â

Japan, a volcanic archipelago situated next to a major seabed fault, is one of the most seismically active regions of the world. Huge tidal waves, known as tsunami, often accompany the earthquakes. Hundreds of earthquakes occur every year in Japan. Nature here is strong and uncontrollable. It smashes cities, floods them, blows them down. Godzilla, the monster that arises from the deep sea and comes to destroy Tokyo, simply incarnates the forces of nature. The Japanese are used to rebuilding their world. And in Arikawaâ ™s view, this enhances their capacity to innovate.

The typhoon was causing the window of his office to shake. Turning to the future, I asked Arikawa if his work had implications for robotics. â œOf course,â he said, â œwe supply our data to robotics people, but I myself do not contribute to it directly.â This prompted me to ask what he thought about the scientific view of animals as machines. Referring to Descartes, I asked whether he saw butterflies as machines.

â œHmmm,â he said. â œThe materials which make up the butterfly body are quite different from those of a machine. Our bodies are also machines in some sense. So we have to know that. Our minds, and the minds of butterflies if they exist, are produced by the activity of brains. And I think that our emotions, or our thinking, all emerge from the activity of brains. So if we say that the brain is a biological machine, then butterflies are like machines.â

â œAnd we are, too?â I asked.

â œWe are, too. But our body is nothing like any presently existing machine, like computers or copying machines, or cars and airplanes. No, there is some fundamental difference. Yet I think it is also continuous, with no clear border between our system and machines. I donâ ™t know if we can really reproduce animals by manufacturing pieces of stuff, but we biologists do want to explain how our mind is constructed, or produced, on the basis of brain activity. At least I have been trying to understand that.â

I asked how long he thought it would take people working on robotics to build a butterfly, complete with sophisticated color vision and intricate neurology. â œThe problem is that they are not aiming at producing butterflies, or living stuff as is,â he replied. â œThey want to extract certain functions from animals to use for human life. If they really tried to make this animal, for funâ ¦â He paused. â œâ ¦well, one hundred years.â

A century to make a butterfly! Arikawa was clearly confident in the power of science. I had difficulty believing it. But I thought that if anybody was going to manage to build a butterfly, he or she might well be Japanese. As British designer Andrew Davey recently remarked:, â œThe miniaturization of form twinned with the maximization of function is a Japanese specialty. It is a hallmark of Japanese design.â

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ARIKAWA OFFERED TO SHOW US some living butterflies. We went downstairs and left the building. Outside, the rain was abating, though the winds were still strong. We got into his car and drove a short distance to his laboratory situated in a prefabricated single-story building. This time, we took off our shoes and put on slippers in the entrance. Arikawa showed us around the sophisticated machines that measure the spectral sensitivities of butterfly eyes. Such research requires stripping the wings from butterflies, tying the living insects to an apparatus, and inserting microelectrodes into their eyes. I asked Arikawa if he thought butterflies feel pain.

â œI donâ ™t think so,â he replied, â œbecause they do not change behaviors when they have an injury on the eye; they do not do anything. So there is no clear sign that they are really feeling pain. At least, when you put a hole in the cornea, or break wingsâ ”butterflies often have broken wingsâ ”itâ ™s perfectly fine.â

I was left with doubts on this subject, remembering what Martin Giurfa had told me about bee nervous systems secreting opioids, presumably to induce analgesia. But I decided not to press the point. For the moment, invertebrate rights are not high on many agendas.

We walked into another room where six graduate students were working away on computers. They said nothing and concentrated on their work. Arikawa went over to a netted box containing several yellow swallowtail butterflies and some vegetation. He grasped one around its thorax between his thumb and index finger and held it out for us to see. It had intricate and beautiful patterns on its wings.

Then Arikawa showed us some adult silkworms. These peculiar animals are moths that have been cultivated for their capacity to produce silk when they are in their larval stage. Once the males become adults, all they do is remain immobile until they smell the pheromones released by females; then they copulate. The females lay eggs. Adult silkworms never eat. They copulate, lay eggs, and die. Thatâ ™s all. Arikawa placed four male silkworms on a brown piece of paper. They looked like white moths with stubby wings. They did not move at all. But when he sprayed them with a vial containing female pheromones, they buzzed into action, beating their wings and moving around in circles on the paper.

Arikawa said the silkworms had been given to him the previous day by a colleague with whom he had co-taught a public science class. I asked if he enjoyed communicating with the general public. He replied that participating in exercises of democratic science came with his job, and that he liked stimulating peopleâ ™s interest in moths and butterflies. I asked how he felt about science dealing increasingly with money, rather than free knowledge for people.

â œYes, thatâ ™s sad,â he said. â œI would say the purpose of living is to entertain ourselves, to enjoy life. So the question is: How can we enjoy life, or do what makes us happy? Making money is one of these things, so itâ ™s important, and it makes life very convenient, by using cars and such items. But I want to put on the same list of what entertains people, enjoying music, or reading novels to stimulate your brain. And science must be regarded as music, as an important piece of social entertainment for human life. Thatâ ™s why I like democratic activity.â

Later that afternoon, Beatrice and I made our way back to Tokyo. The typhoon was coming to an end. The rains had ceased. Hundreds of broken plastic umbrellas lay strewn around the waste bins in front of Shinjuku subway station. As we walked around town, the setting sun burst through an opening in the clouds and illuminated the city sky in pink and purple.

At one point we went into a store and admired the sophistication of the latest electronic gadgets. Several lifelike mechanical animals caught my attention, in particular a small green bird that chirped different melodies when the photosensitive cell on its chest was stimulated. When it sang, it moved its beak, shook its head and wagged its tail. I thought about butterflies, with photoreceptors on their tails. And Kentaro Arikawaâ ™s words came to mind: â œThere is no clear border between ourselves and machines.â Butterflies see better than we do in some respects, though their brains are mere specks two millimeters in size. Their tiny brains can even adjust their interpretation of colors in function of light. Fancy circuitry in the butterfly brain must be involved, but for the moment its details remain unknown.

Butterflies are transformers as they metamorphose from worm into winged insect in the pupa. People in Japan are transformers, pushed by volcanoes and history to innovate and renew themselves. Shamans are transformers, changing into animals in their minds. Every living creature is a transformer, the result of a long series of transformations through evolution, which is ongoing. Every living cell is literally a transformer, transforming charges between the outside and inside of its membrane. Life itself is a transformer; it diversifies, unfolds, and morphs, and takes on as many incarnated forms as possible. And machines that act like animals are transformers, halfway between machines and living beings.

Kentaro Arikawa said there are no clear borders between ourselves and machines. He said this with complete serenity and without regrets. We ourselves are the products of the machines that are our bodies and brains, he saidâ ”without regrets, because machines can be beautiful, and have even started acting like biological creatures. As I thought about this point of view, a reformulation of Descartesâ ™ dictum came to mind: â œI think, therefore I am a machine.â But I did not agree.

Chapter 10

Mystery Jelly

After traveling to Japan, I began searching for natureâ ™s *chi-sei,* or *capacity to know*â ”rather than *intelligence.* I wanted to know how nature knows.

Bees handle abstract concepts, slime molds solve mazes, and dodder plants gauge the world around them. These species demonstrate a capacity to know, but they do not speak in human tongues and cannot tell us about their knowledge. Their capacity to know remains elusive. Humans, on the other hand, are good at talking. And we are also a natural species. *Homo sapiens sapiens* has a brain remarkably similar to those of other mammals. In fact the human brain has the same basic architecture as all vertebrate brains. In the absence of barriers between humans and other species, it dawned on me that I could approach natureâ ™s capacity to know by considering how humans know.

Descartes could place only one thing above doubt, namely his own existence as a thinking subject. â œI think, therefore I am,â he wrote. This prudent stance inspired me to focus on how I know.

I thought of myself as an organism. The word comes from the Greek *organon,* meaning tool. As an organism, I am a kind of tool. And I have organs, which are also kinds of tools. My heart pumps, my kidneys filter, my hands grasp and look like tools. But does this mean that humans are machines?

Descartes thought so. He described the human body as a machine made of separate mechanical parts. He compared nerves, muscles, and tendons to rubber tubing. Writing in the midâ “seventeenth century, he likened lungs to windmills and described the nervous system as a network of fine nets that starts in the brain and spreads from there to the rest of the body. In his book *The Treatise of Man,* he wrote: â œAll the functions I have attributed to this machine, such as the digestion of meat, the beating of the heart and arteries, the nourishment and growth of the members, respiration, waking and sleeping, the reception by the external sense organs of light, sounds, smells, tastes, heat, and all other such qualities, the imprinting of the ideas of these qualities in the organ of common sense and imagination, the retention or imprint of these ideas in the memoryâ ¦follow naturally in this machine entirely from the disposition of the organsâ ”no more nor less than do the movements of a clock or other automaton, from the arrangement of its counterweights and wheels.â

I mulled this over and went running in the woods near my home. Autumn colors, yellow and red, were blending in with the greenery. I visualized myself as a kind of machineâ ”a butterfly machine moving through the landscape, perceiving colors through my eyes. I jumped over fallen trunks and branches strewn across the path. I knew my eyes had fewer photoreceptors than those of a butterfly, but I could see well enough to run through the forest without falling down. I knew of no human-made machine capable of doing this.

Since Descartes, the mechanical view of living beings including humans has enjoyed popularity among scientists and philosophers. But living beings differ in fundamental ways from the mechanical devices built to date. We can reproduce ourselves and we can grow and transform ourselvesâ ”while computers, toasters, and automobiles are incapable of such feats. When my parentsâ ™ ovum and sperm fused, they formed a single cell. This fertilized egg gradually grew into a human-shaped embryo through a series of duplications, at first into undifferentiated and nonspecialized cells, then into cells as diverse as neurons, blood cells, and skin cells. As my embryo transformed itself in this way, I came into being, a transformer from the get-go. Now, decades later, my body continues to repair its wounds and still becomes more resistant as I use it. In all of this, I am like countless other organisms and unlike the overwhelming majority of human-built devices.

True, humans are starting to design technologies that emulate the ways of nature. But so far, among all the devices made of metal alloys, silicone, plastic, and rubber, there is nothing really equivalent to living beings made of living cells. Each individual cell in a body is alive. Living cells are themselves creatures with a life cycle, and they must look after their own survival by adapting to the circumstances they encounter. This vital aspect of all biological creatures is absent in machines such as computers, the elementary particles of which are inert materials. Computers may now greatly exceed the computational capacities of humans. And they may now be endowed with â œartificial intelligence,â meaning to say that they can be programmed to do things that would otherwise require intelligence if done by a living organism. But this does not mean that machines are alive in the biological sense. It means that they can be made to exhibit certain characteristics usually associated with life.

Some computer programs can generate informational entities that reproduce, evolve, and mutate, all the while competing with one another. These forms of â œartificial lifeâ function in ways comparable to living organisms. But computer programs written with sequences of ones and zeros (representing voltage on and off) cannot move around and feed themselves in the material world, and are not equivalent to living beings like bacteria, birds, and humans.

I do not know if machines know, but my impression is that I do. How does knowledge come to me? My knowing self seems to me to be lodged inside my head, behind the eyes, slightly above nostril level. And contemporary science confirms that a large part of human knowledge, including experience, sensation, and thought, is mediated by our brains.

The human brain has the consistency of jelly. According to some estimates, it contains about one hundred billion nerve cells, or neurons. Each neuron can form thousands of links with other neurons. This means that the human brain has many times more connections than stars in our galaxy. How such a complex network takes shape in an organism that originates as a single cell defies current understanding.

Scientists estimate that a cubic millimeter of the brainâ ™s cortexâ ”a sphere small enough to fit inside this *o*â ”contains over two miles of connecting neural â œwireâ (or the extensions of neurons known as axons). I tried forming an image of this in my mind but failed repeatedly. I found this difficulty was compounded by knowing that I was using my own brain to consider the matter. Conducting an inquiry with the very object of inquiry can be tricky. The human brain can have difficulty thinking about itself.

When I look at the world around me, I see three-dimensional, color images accompanied by sensations of sound, taste, smell, and touch. These images look like they are outside my head, but they are actually a reconstruction operated by my brain. How do pictures emerge from the gelatinous matter which is my brain? How do images form inside pinkish gray jelly? The mystery is not new, and remains unsolved.

Since the 1990s, scientists have generated vast amounts of new information about the brain and mind thanks to innovations in brain-imaging techniques. Using functional magnetic resonance imaging (MRI), scientists can now peer inside the thinking, feeling brain, and see it in action. Magnetic scans work by revealing increased oxygen-rich blood flow, which occurs when a particular location of the brain is engaged in a specific task. A researcher need only put a few people into the scanner and ask them to think of an idea or behave in a given way. After subtracting the brain areas that are active in performing basic tasks, the machine depicts the brain areas critical to the task at hand as splotches of light on a screen. The neurons involved in identifying the color red, or recognizing a face, or adding a sum, or categorizing apples as fruits, light up on the screen like magic. Such research has led to a clearer understanding of the brainâ ™s spatial organization. For instance, scientists have shown that children who learn a second language use overlapping brain areas when speaking the two languages, while those who learn the second language later in life use a distinct part of the brain for the second language. This holds true for Chinese people learning English or for Italians learning Hindi.

Brain imaging shows that most of the brain works at one time or another during the day. Though some functions require the activity of only small parts of the brain, most complex behaviors or thought patterns use many different brain areas. Thinking of an alpine landscape activates one network of brain areas, while thinking of cats lights up an entirely different network. Once the thought is over, all the activated neurons fall silent. Brain imaging reveals that each different thought lights up neurons in its own specific combination.

However stunning these results may be, pictures showing splotches of light on a screen do not explain how the brain works. Just because certain neurons are correlated with a behavior does not mean they cause it. Increased blood flow in a specific part of the brain as revealed by a magnetic scan merely indicates that active neurons, which require extra energy to do their jobs, are sucking in glucose and oxygen from the blood. This does not say much about how we experience what we experience. The fact that your neurons are using glucose and oxygen does not explain how you see an image of the words on this page.

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By observing people with localized brain damage, scientists have long known that the human brain is divided into modules that perform separate tasks. The part of the mind that sees, hears, and thinks is often associated with the top layer of the brain called the cerebral cortex; this includes the frontal lobes, which are involved in making plans and assessing risks, and the visual cortex at the back of the head, which processes visual information. Recent research using brain imaging has confirmed this modular understanding, showing that precise, and sometimes surprisingly small, groups of brain cells work in concert to carry out highly specialized functions.

Brain imaging has also revealed the importance of the brainâ ™s deeper layers, known as the â œemotionalâ brain. Most in-coming information, including what we see with our eyes, is initially processed by the deeper parts of the brain before being relayed to the upper levels. For example, visual information first goes to a small cluster of neurons in the center of the brain known as the thalamus, then down to the amygdala, a small almond-shaped structure that mediates instinctive fear. The information is also relayed from the thalamus up to the cortex, but by a longer, slower route. This arrangement explains how we sometimes respond to potential dangers before we become fully conscious of what they are. For example, we recoil from a snake on a forest path before we have an awareness of seeing it, because our emotional brains jolt our bodies into action. This capacity for rapid response may not be very preciseâ ”sometimes the snake is only a stickâ ”but it provides obvious survival benefits. We are wired for survival, to a certain extent.

Magnetic brain imaging also reveals that our minds are on a kind of neural tape delay. For example, the areas of our brains involved in recognizing objects show peak activity before we ourselves recognize objects. The human brain appears to construct conscious awareness in an after-the-fact fashion. People perceive events about eighty milliseconds after they have occurred, just a bit longer than the blink of an eye. The brain appears to use this time lag to carry out fancy editing tricks. For example, when I snap my fingers, the sight and sound of the snap are processed in different parts of the brain and at widely different speeds, yet they seem simultaneous to me. I am never aware of what is happening now in my brain, but only of a small part of what has just happened there.

Furthermore, the brain is not limited to the skull. My gut alone contains about one hundred million neurons capable of learning, remembering, and responding to emotions, just like the larger brain in my head. These neurons form tissue networks, which line the esophagus, stomach, small intestine, and colon. The gut brain and the head brain are interconnected and work together. My body as a whole sends a constant flow of signals to my brain, and this largely influences my experience of the world. Knowledge about the world comes to me through information I get from my senses and through my bodyâ ™s experiences. My body moves about in the world and verifies what I think I know.

Peopleâ ™s bodies sometimes know things before people themselves do. In a controlled experiment, scientists asked people to draw cards from four decks, two of which were heavily skewed with penalties. Skin measurements showed that people contemplating the bad decks began sweating more profusely before they themselves could verbalize an intuition about which decks to avoid. Such research shows that emotions are a mix of brain states and body experiences, which include increased heart rate, hormonal activity, and input from the gut brain. It also shows that the body plays a role in the reasoning process. Having a gut feeling is not just a metaphor.

We often think of emotions as mental phenomena, but many emotions require the body to play themselves out. People may feel fear in the pits of the stomachs, or love in their hearts. And when they are deprived of all bodily sensations, they have difficulty experiencing emotion; for instance, people suffering from â œlocked-in syndromeâ â ”which means they are so thoroughly paralyzed that they can only communicate through eye movementsâ ”report an astonishing lack of fear about their condition. According to neurologist Antonio Damasio, this is because they have no way of using the body as â œa theater for emotional realization.â

Though the brain and body work together to know the world, the brain seems to be the key organ that people use to articulate and store their knowledge. Our brains harbor our minds and memories. But what is mind? And what is memory? *Mind* derives from the Old English *gemynd,* meaning memory or thought, and stems from the Greek *mnasthai,* meaning to remember. Mind and memory go together.

Most current theories say that long-term memories are determined by the ways in which neurons connect with one another. Connections between neurons are called synapses. A synapse is a gap, a small space where neurons exchange chemicals known as neurotransmitters. When a neuron communicates with a neighbor, it fires an electrical impulse down its body to the synapses, where it causes the influx of charged calcium atoms; this in turn triggers the release of neurotransmitters, which squirt through the synapses over to the receiving neurons, where they set off new electrical impulses. Recent evidence suggests that synapses strengthen and even duplicate if they are used frequently, and weaken and become less efficient at transmitting charges if they are not used.

Research also reveals that all species with brains, from snails to humans, change the synaptic connections between neurons when they learn and remember. And to carry out these changes, they use the same molecules. Humans are united with other species down to the memory bank and back.

Many scientists now believe that memories are formed and stored in the brainâ ™s pattern of synapses. As each neuron in the human brain can have up to ten thousand synapses, the overall brain can take on almost limitless configurations. Memory appears to be stored in the entire cerebral cortex and to be consolidated through synaptic change in neuronal networks. When our synaptic connections get stronger because we have just learned something, our neurons activate their DNA and synthesize fresh proteins. Scientists now suggest, mainly extrapolating from research on rat brains, that knowledge and memories are etched onto neuronal circuits in this way. Likewise, there is evidence that each time an old memory is brought to mind, the brain consolidates it by making new proteins, before putting it back into storage.

It is possible for a human to experience this consolidation, for example, by learning a text by heart, then forgetting it again, then repeating the cycle several times, memorizing it in a fairly permanent way in the end.

Short-term memories, which only last up to a minute, do not appear to require protein synthesis. Neuroscientist Barry Connors describes short-term memory as â œa dynamic, ephemeral process that has not yet yielded to molecular characterization.â

Long-term memories have recently been associated with the formation not only of new proteins but also of new neurons. For decades, scientists used to believe that the brains of adult animals could not change. But now they have discovered that all animals, including humans, grow new neurons throughout their adult life. And by studying the brains of adult rats, scientists have found that these new neurons are essential for at least one type of memory, fear. Research also indicates that acquiring new knowledge increases the survival of new neurons. Learning, it seems, rejuvenates the brain, from rats to humans.

Recent research on memory has made important discoveries but falls short of explaining how new proteins, strengthened synapses, and new neurons relate to precise memories we can call to mind, such as an image of the Mona Lisaâ ™s face, or a Beatles melody, or the name of Franceâ ™s capital city. After all, proteins, synapses, and neurons are not images, melodies, or names but components of the gelatinous matter that makes up our brains. The mystery remains as to how brain jelly can generate constructs such as mental images. Nevertheless, it now seems established that physical changes in the brain underlie the mental capacities of learning, remembering, and knowing.

Scientists are finding it difficult to learn how the brain learns. According to neuroscientist JoaquÃn Fuster, cognitive information requires the activation of â œwide, overlapping, and interactive neuronal networks of the cerebral cortexâ in which â œany cortical neuron can be part of many networks, and thus of many precepts, memories, items of experience, or personal knowledge.â And physiologist Eilon Vaadia writes: â œIt is widely accepted that large areas of cortex are involved in any behavioral process, and that these areas contain many modules, each consisting of groups of cells that process specific information. It is often assumed that, once the brain matures, each module and each cell fulfills one specific function. But accumulating evidence indicates that this may not be so. Instead it is likely that each cell participates in several different processes. The brain is also constantly changing, and each cellâ ™s effects may be rapidly modified. So it is essential to study a large number of neurons simultaneously to understand how cells communicate and how neuronal interactions are modified in relation to learning and behavior.â

The brain is malleable by nature, otherwise we would neither learn nor know. It wires itself in different ways depending on the experiences we have and the skills we acquire. For example, brain imaging of string musicians shows that the area of cortex that governs the fingering hand is larger than that of the other hand, and that the most-used fingers take up the largest space. There is also increasing evidence that the brain can reconfigure itself when impaired. Brain imaging shows that people who have regained use of a limb after a stroke in their motor cortex have learned to use many distinct parts of their brains in a coordinated fashion to make up for the inactivity of the damaged area. And dyslexic children can learn, by hearing sounds slowly and many times over, to change their brains and use different regions to process language. Some people can even exercise themselves out of paraplegia, because slow and patient exercise allows new parts of their brains to learn to take on the tasks no longer fulfilled by the damaged parts.

Our brains are built to soak up knowledge. They are wired for change. They are transformers. Descartes emphasized that knowing about the world involves having a first-person self. *I* think, therefore *I* am. Knowledge and self hang together. But knowing beyond doubt that I exist as a thinker of thoughts says little about the nature of â œI.â And since Descartes, no one has managed to explain how a conglomerate of cells turns into a self.

Having a self corresponds to most peopleâ ™s most basic experience in the world. We refer to ourselves as â œIâ or â œme,â and do not doubt our own existence as such. Yet some contemporary philosophers and neuroscientists posit that the unitary â œIâ is actually an illusion concocted by our brains. They justify this stance by pointing out that research has failed to reveal a centralized spot in the brain where the self exists. According to this view, we are at best a bundle of selves associated with many different brain configurations. They see the unitary self as a â œchimera,â an entity â œdevoid of self-nature.â In this view, the feeling I have of being a self is in fact a series of systems formed by billions of neurons that merely feels like a self.

Philosopher Colin McGinn points out that this argument â œassumes that we know more about the brain and the self than we really do. Our current knowledge of the brain does indeed reveal no unifying physiological principle to correspond to the idea of a unified self, but that is equally interpretable as showing that our knowledge is very limited, not that there *is* no unified self.â It does seem hasty to conclude that we ourselves do not exist.

I do not doubt that I exist. As I sit here typing these words, watching my fingers move over the keyboard, I know I am somewhere inside my body. Since the beginning of this book, I have been choosing the words. I can hear them ring in my mind before my hands type them out. I have conducted this inquiry from my point of view throughout. And you, when you read these words, you know that you are reading them. But all this does not change the fact that we still do not understand the nature of the self.

The problem may stem from a confusion of explanatory levels. The brain is the physical underpinning of the mind, but the two should not be confused.

Having a healthy brain certainly helps having a wholesome sense of self. People who have sustained brain injuries can lose their sense of self, or feel they are in the wrong body, or believe they are several people at the same time. But this does not dissipate the mystery. Though most people with healthy brains feel sure they have a self, nobody really knows just what a self is.

Progress so far in neuroscience has been compared to the accomplishment of the Wright brothers, who flew the first airplaneâ ”if the goal were to reach the moon. When Orville Wright first took off in 1903, he flew one hundred and twenty feet. It took sixty-six more years before humans walked on the moon. Research on the brain and mind is in its infancy.

Being gelatinous and highly malleable in its functioning, the brain is unlike any known machine. The activity of neurons, as currently understood, does not explain how we see images in our heads. We know neither who we are as knowing selves nor how the mysterious sense of self emerges in a biological organism. Understanding the human capacity to know is only just beginning. For the moment, no one really knows how mind and knowledge spring out of the gray, fleshy matter inside our skulls.

Chapter 11

Chi-Sei and Knowing Nature

Nature uses signs, many of which escape our eyes. A sign is something that stands for something else. The DNA and RNA molecules contained in living cells can have several functions, one of which is to stand for the sequence of amino acids in proteins. DNA and RNA signs carry information according to an arbitrary system in which every â œwordâ has three â œletters.â Science has only recently begun to study signs in nature.

Shamans have long said that nature uses signs and communicates. Taking their insights into consideration could improve scientistsâ ™ understanding of nature.

Individual cells communicate using protein signals and other molecules to relay information to one another. Plants communicate with volatile chemicals, while butterflies use ultraviolet signs, and dolphins use underwater sound waves. Humans communicate with language. Plants and dolphins cannot speak our language, and we have difficulty communicating with them. But this should not stop us from recognizing that many living beings spend a lot of time communicating. Information of one sort or another is constantly circulating in nature, in particular in the form of biochemical molecules. The world is streaming with signs.

Not so long ago, some people considered the use of signs a specifically human trait. But defining human specificity by listing traits that only humans possess has turned out to be a difficult exercise: Either some people do not exhibit the trait or else members of some other species do. People in Western cultures have obsessed about the difference between humans and animals. But humans are animals, and our capacities grow out of our common past with other species. So why conceive of ourselves as entirely separate from them? Why the obsession to look for the human distinction?

Japanese semiotician Yoshimi Kawade wrote in 1998: â œThe Western mind draws a sharp boundary between the human and the rest of the world (also between the human and God); for Japanese, that boundary is much less clear-cut, especially between the humans and animalsâ ¦for the Western mind, it is hard to recognize mind in animals, whereas for the Japanese mind, it is hard not to do so.â

But the situation has since grown less clear-cut. Western scientists have recently generated a mountain of data demonstrating that humans have kinship with other living species. What may still be lacking among Westerners is a willingness to accept the consequences of this kinship. And Western languages may lack the appropriate concepts to think it through.

I launched into this investigation seeking to understand â œintelligence in nature,â but gradually realized that *intelligence* has so many different meanings that trying to define it does not seem intelligent. In Japan I realized that the Japanese word *chi-sei,* meaning knowing-ness or recognizing-ness, provides a workable alternative.

In English, *to know* and *to recognize* are related. The verb *know* comes from Old English *cnawan,* meaning â œrecognize, identify.â Its first definition in *Websterâ ™s Dictionary* is â œto apprehend immediately with the mind or with the senses; perceive directly; have direct unambiguous cognition of.â A slime mold in a maze has the capacity to apprehend its situation and act on its knowledge. It can take in many different variables about the world around it and make a decision that enhances its survival. It has *chi-sei.* But is this *knowing-ness,* or *recognizing-ness*?

Recognizing-ness does not exist in dictionaries, whereas *knowingness* does. At first I thought it might be the clear concept I was looking for as an alternative to *intelligence.* But on closer inspection, *knowingness* is associated with the adjective *knowing,* which the *Oxford English Dictionary* defines as â œsuggesting that one has secret knowledgeâ and as â œ(chiefly derogatory) experienced or shrewd, especially excessively or prematurely so.â This was not the kind of knowingness I had in mind.

I considered *know-how* as a translation for *chi-sei.* But it means â œexpertise,â which itself means â œgreat skill or knowledge in a particular field.â *Chi-sei* is about knowing how, but *know-how* does not mean this.

I also tried *apprehension, cognizance,* and *understanding,* but none fit the bill. *Apprehension* means â œanxious or fearful anticipation.â *Cognizance* refers to â œthe action of taking judicial notes,â or to a â œdistinctive mark worn by retainers of a noble house.â

Even an apparently simple word like *understand* is loaded. Its first meaning is â œto perceive the intended meaning of (words, a language, or a speaker).â

I did not find an English word equivalent to *chi-sei* that could apply neutrally to other species. Intelligence, awareness, cognizance, and understanding were all defined in human terms. Faced with the absence of an appropriate word, I decided to import *chi-sei* into English, meaning â œcapacity to know.â Yes, a Japanese import.

When I talked about intelligence and *chi-sei* with an American neuroscientist friend, Valerie Stone, she encouraged me to think in a new direction and to consider *chi-sei* in contrast to something like the operation of a thermostat. This device, which switches heat on when it gets too cold and off when it gets too hot, has sensors for detecting temperature and internal wiring to control its â œbehaviorâ and â œdecisions.â By a basic definition of intelligence, such as making appropriate decisions, a thermostat appears to display â œintelligence,â she said. And as a thermostat appears to apprehend its immediate environment and act on that apprehension, it also appears to have a basic form of *chi-sei,* the capacity to know. But granting these faculties to this nonliving device rests on a fallacy. A thermostat can only interact with its environment because a human has programmed it. It has no real way of solving problems, such as â œtoo hotâ or â œtoo cold,â by itself. Behind a thermostatâ ™s apparent â œintelligenceâ or â œcapacity to knowâ lies human intelligence and knowledge.

There is a further difference between what slime molds and bees do and what a thermostat does. Stone also pointed out that thermostats change behavior according to a very simple mechanism that never varies, whereas organisms act flexibly. The single-celled slime moldâ ™s behavior is interesting, she said, because it can solve *new* problems, using a computational mechanism we donâ ™t understand yet. It uses much more computation than a thermostat and shows much more flexibility. And a butterflyâ ™s visual system can solve the problem of color constancy even in new lighting conditions. Life forms have a capacity to know, which is creative, whereas a thermostat tends not to do anything new.

Chi-sei and the flexibility that goes with it require a capacity to process information. According to Toshiyuki Nakagaki, the scientist who showed that slime molds can solve mazes, and who introduced me to the concept of *chi-sei*: â œThe brain is an interesting object in that it is an excellent computer, but we donâ ™t know how it functions. And we donâ ™t know how brainless microorganisms perform information processing. In fact, what we really donâ ™t know is the extent of the capacity of the microorganism to process information.â

Scientists have begun to study information processing in brainless multicellular organisms such as plants. Plant cells relay information to one another using signals such as charged calcium atoms. Our neurons do the same. Plant cells also have their own particular signals, which tend to be relatively large and complicated proteins and RNA transcripts. These molecules swim around the plant providing information from cell to cell. Individual plant cells also appear to have a capacity to know.

So do cockroaches. Research shows that these insects detect approaching predators by sensing minute air movements, and that they have neurons in their brains which fire at a rate that varies with the wind. Given that air movements change when a predator approaches, this sensing capacity allows cockroaches to surmise the direction of an attack and scurry away to avoid being eaten.

For a cockroach, the world is not pregiven, or defined in advance. A cockroach can perceive the world and take action in it, and its perception is inseparable from its sensorimotor capacities. It *knows* because it is *informed* by its body and brain about the approach of predators and *embodies action* by scurrying away. This is no simple or merely reflexive process. The cockroachâ ™s nervous system decrypts the dynamics of minute air movements and sets in motion preventive action at the level of the whole organism. Just being a cockroach and coping with the world in order to stay alive requires *chi-sei.*

Simple organisms can compute. But there is more to knowledge than computation. Computers are better at computing, and even playing chess, than humans. But this does not mean they have *chi-sei.* Chess-playing computers use mindless number crunching to figure out what move to make. For machines, playing chess better than a world master does not require a capacity to knowâ ”except in the humans who designed and built them. Building a machine capable of an apparently simple task, such as walking around obstacles, turns out to be much more difficult than designing a number-crunching machine capable of playing world-class chess.

Machines that act on their computations and ensure their day-to-day maintenance and survival in a changing environment could be said to have *chi-sei.* But such machines, inasmuch as they exist, cannot do without being programmed. Nor can machines design and construct improved versions of themselves.

Machines may lack *chi-sei,* but the cells in our bodies do not. They constantly make decisions, responding to a variety of electrical, chemical, and tactile factors, so as to grow and differentiate in a coordinated way. Cells communicate with one another through â œsignaling pathways,â which include dominolike cascades of proteins and a wide variety of signals with meanings such as â œstay alive,â â œkill yourself,â â œrelease this molecule youâ ™ve been storing,â â œdivide,â and â œdonâ ™t divide.â Any given cell receives hundreds of signals at any one time and has to integrate them before acting.

The human body is an edifice made of about one hundred trillion cells that communicate with one another through an exchange of chemical signals. Human cells use about eleven thousand signaling proteins. They communicate using a chemical sign system that scientists have only started decoding.

According to biologist Julian Downward, â œAll cells must continually sense their surrounding environment and make decisions on the basis of that information. Single-celled organisms must be able to tell which nutrients are nearby and regulate their metabolic processes accordingly. Cells in multi-cellular organisms such as ourselves must sense the presence of neighboring cells and hormones when making decisions such as whether to proliferate, move or die. These processes all require the transfer of information from detection systems referred to as receptors through intermediate molecules within the cell, to cause changes in the expression of genes and the activity of enzymesâ ¦Cells receive inputs from many signaling pathways at the same time and must interpret them together, in the context of each other, before making decisions. There are several known ways in which cells do this, although this is an area where much work remains to be done.â

Even bacteria communicate. It turns out that all bacteria species relay information to one another in a â œbacterial Esperanto,â which they use to work together. For example, some six hundred species of bacteria coat your teeth every morning, forming a bio-film by positioning themselves in exactly the same order every time. To do this, researchers surmise, they must be able to distinguish self from other. Bacteria use chemicals rather than words to communicate, but this does not stop them from acting efficaciously.

Some bacteria communicate with one another to determine how numerous they are and only launch an attack once they form a group large enough to fight their hostâ ™s immune system. They like to gang up on their victims.

Some bacteria are particularly crafty. When a *Salmonella* bacterium first approaches a host cell, it produces at least ten proteins, some of which end up inside the host cell, where they trigger cascades of reactions. One of these proteins switches on critical protein regulators of host cell shape. This causes ruffles and convulsions in the host cellâ ™s membrane, which engulfs any *Salmonella* present. Another *Salmonella* protein switches off the same regulatory proteins. A *Salmonella* bacterium breaks into cells like a bandit with a pair of keys. It acts with cheeky *chi-sei,* and it can also kill.

All cells are largely made of proteins. If individual cells including bacteria have a capacity to know, what about proteins? Some scientists seem to think so. Biochemist Christopher Miller writes in the journal *Nature:* â œProteins are intelligent beings. They have evolved to operate in the metabolic maelstrom of a turbulent cellular environment. Transcription factors must know when to switch genes on or off, and the cellular levels of specific â ˜signalingâ ™ moleculesâ ”lactose, retinoic acid, tryptophan or copper, to mention a few casesâ ”-give them this information. Likewise, enzymes at key biochemical control points have to speed up or slow down according to the ever-changing demands, coded in concentrations of cytoplasmic metabolites, of, well, life. Haemoglobin, the granddaddy of all such â ˜allostericâ ™ proteins, knows when you are sleeping or sprinting, realizes whether you live on Cape Cod or in Kathmandu, and ascertains moment by moment whether it is coursing through your lungs or visiting vigorously respiring tissues; it makes these judgments and accordingly adjusts its conformation, and thus the bloodâ ™s oxygen-carrying behavior, by sensing cellular solutes such as CO_2, H^+, Cl^-, NO and bisphosphoglycerate.â

Whether proteins truly have a capacity to know is ultimately a matter of opinion. Proteins are merely folded chains of amino acids. In my view they behave as if they have the capacity to gauge a wide variety of variables and take appropriate and precise actions. If they did not, we would not be alive. But my mind boggles when I think about the *chi-sei* of proteins. How could a string of amino acids know anything? Amino acids are simple organic compounds that contain a carboxyl group (-COOH) and an amino group ($-NH_2$). They are not much more than a configuration of atoms. Yet scientists report that proteins â œrecognizeâ the molecular pattern of specific pathogens. They also â œrecognizeâ DNA damage, and either â œrepairâ it or, if the damage is too extensive, â œsend a signalâ to the cell to kill itself. One protein, ubiquitin, does everything from â œdegrading defective proteinsâ and â œdirecting protein trafficâ to â œregulating DNA activity.â Ubiquitin is no simple, mechanical device. It knows its way around the cell. How it works is the question.

I asked Thomas Ward, a professor of chemistry at a Swiss university and a protein specialist, whether he thinks proteins have a capacity to know. He replied, â œA protein can move, powering itself from an external food source. A protein can interact with others of its own species, as well as with individual entities from other species, such as DNA and RNA molecules. A protein can use other entities to build a large edifice, such as a cell. A protein can even reproduce itself, according to recent research. A protein can lose all of its functions, or â ˜die.â ™ The foremost function of proteins is to recognize. For example, they recognize RNA molecules, or viruses, or other proteins. Then, based on this recognition, they can take appropriate measures. If this is what you mean by â ˜to know,â ™ then I find proteins undeniably have the capacity to know.â

When I first started this investigation, I expected scientists would consider my interest in natureâ ™s â œintelligenceâ with suspicion. But this turned out not to be the case. Science seems to have evolved in recent years. Now few scientists describe proteins as stupid bits of matter involved in automatic reactions. There are too many clear indications of a capacity to know all through the edifice of life. Tens of thousands of scientists in many different countries are busy studying these indications and trying to discover how nature knows. They study cell signaling, or DNA repair by protein-enzymes, or neuron decision making, or slime mold maze solving, or a dodder plantâ ™s capacity to gauge its environment. The data they generate is a treasure trove of *chi-sei.* Scientists now confirm what shamans have long said about the nature of nature.

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TRANSFORMERS AND TRANSFORMATION kept cropping up during this investigation. My hunch is that part of natureâ ™s essence is to transform itself, to evolve. The beings of this world seem driven to transform themselves, one way or another. By conducting this investigation, I was transformed. My understanding of science changed. I used to think that scientists were dogmatic, particularly when it comes to considering other species as anything other than machines. Instead I found a broad base of scientists studying biology with open minds.

I also look at living beings with new eyes. Learning that plant cells send one another signals similar to those used by my own neurons, and that plants gauge the world around them and make appropriate decisions, has made me look at all plants, including weeds, with increased respect. And now I admire slime molds, appreciate nematodes, fear *Salmonella,* and respect cockroaches. And when I drive in the summertime and insects crash into the windshield, I know too much.

Now other species seem more human to me, and humans seem more natural. Recognizing that the capacity to know exists outside humanity leads to a richer, more adventurous, and more comfortable life. Instead of trampling blindly all over the planet, we can see that lifeâ ™s prodigious powers are housed in all its denizens. *Chi-sei* forms a continuum across the living world.

There does seem to be one difference between contemporary humans and other species: we accumulate our knowledge outside ourselves in artifacts such as written texts. This greatly accelerates the transmission of knowledge, putting us on a learning curve shared by no other species. We acquire and transmit knowledge at an unprecedented rate. But this has given us dominance over most other species, which we are currently abusing by depleting nature at an unsustainable pace. We have yet to learn how to control our predatory nature.

Jaguars set an example on this count. They stand at the top of the Amazonian food chain yet lead discreet lives. As top predators in the rain forest, they can both swim and climb trees with ease; their prey ranges from fish, turtles, and caimans to rodents, deer, and monkeys. These versatile cats often kill their prey by piercing the skull with one swift bite. Their name comes from the Tupi-Guarani word *yaguÃ¡ra,* meaning â œan animal that kills its prey with one bound.â Jaguars have no rivals besides humans, but they tend to hide. In fact, they move around with such stealth that biologists have difficulty studying them. These impeccable predators control their power.

Humanity can learn from nature. This requires coming to terms with the natural worldâ ™s capacity to know. We are a young species, and we are just beginning to understand.

NOTES

INTRODUCTION

P. 2: TESTING HYPOTHESES IS THE METHOD OF SCIENCE

Biophysicist Jacques Dubochet declared in 1997: â œWhat bothers me in the case of Narby, is that his approach goes against what I try to teach my students and what I try to practice with rigor in our research. During the weekly meetings with the doctoral candidates who collaborate with my research, I always have to fight to get them to test their hypotheses. I tell them: â ˜You must set up the test that will destroy what you are trying to set up; you must always try to refute the hypothesis you have just made.â ™ This is the famous scientific method, which puts hypotheses in question. This is a hard way to work, it advances only modestly, and it makes the rigor and difficulty of our profession. Here is an example of this from our current experiences in the laboratory. Our team studies knots in the DNA filament, and our work has led us to formulate an apparently fundamental idea for the mathematical theory of knots, according to which any knot can be precisely defined by the length of the shortest string which constitutes it. My colleague Stasiak put forward this hypothesis after we had studied four or five different DNA knots. Since then, we have had confirmation for his hypothesis with about fifteen other knots. From there, two paths were possible. We could continue to explore the consequences of this idea, which seemed very exciting; this might lead to a method for undoing any knot; or it might explain how some systems tend to self-organize themselves into a more orderly state; one can even imagine that this idea might explain the formation of the solar system, the development of life, and the emergence of consciousness. In my view, this is the path that Jeremy Narby chose, and he charged down it blindly. The other path is more ordinary, less spectacular; it consists of looking for the limits of the idea, looking for the knots to which it does not apply. If the idea remains valid once we have tried to question it in all imaginable ways, then we could consider extending our exploration with a clear conscience. That is the path of scienceâ (quoted in Dubochet et al., 1997, 25â “26). The work on DNA knots by Dubochet and colleagues was published by Katritch et al. (1997).

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p. 2: Three Biologists Work with an Indigenous Shaman

Narby (2001) writes about the scientistsâ ™ experience with the hallucinogenic plant brew called ayahuasca: â œIn interviews conducted in their respective laboratories four months after the Amazonian experience, the three biologists agreed on a number of points. All three said the experience of ayahuasca shamanism changed their way of looking at themselves and at the world, as well as their appreciation of the capacities of the human mind. They all expressed great respect for the shamanâ ™s skill and knowledge. They all received information and advice about their own paths of research. The two women reported contact with â ˜plant teachers,â ™ which they experienced as independent entities; they both said that contacting a plant teacher had shifted their way of understanding reality. The man said that all the things he saw and learned in his visions were somehow already in his mind, but that ayahuasca had helped him see into his mind and put them together. He did not think he had experienced contact with an independent intelligence, but he did think ayahuasca was a powerful tool for exploring the mind. The scientific information and imagery accessed in ayahuasca visions by the three biologists were certainly related to the information and images already in their minds. They did not have any big revelations. Ayahuasca is not a shortcut to the Nobel prize, the French professor remarked. They all said that ayahuasca shamanism was a harder path to knowledge than science, and as scientists, they found specific difficulties with it. For example, getting knowledge from an ayahuasca experience involves a highly emotional, subjective experience that is not reproducible. One cannot have the same ayahuasca experience twice, nor can somebody else have the same ayahuasca experience as oneself. This makes it almost contrary to the central method of experimental science, which consists of designing objective experiments that can be repeated by anyone, anywhere, anytimeâ (303â “4).

Chapter 1

p. 7: Peruvian Amazon as Worldâ ™s Biodiversity Epicenter

Mittermeier et al. (1999) write in their book *Hotspots: Earthâ ™s Biologically Richest and Most Endangered Terrestrial Ecoregions:* â œThe Tropical Andes Hotspotâ ¦is the richest and most diverse biodiversity hotspot on Earth. This was pointed out by Myers (1988) in his first publication on the hotspots, in which he referred to this region as the â ˜global epicenter of biodiversity,â ™ and the current analysis strongly supports his earlier assessment. The Andes mountain range, its different cordilleras, and the vast array of slopes, peaks and isolated valleys provide for a multiplicity of micro-habitats that have led to the evolution of an incredible number of plant and animal species. Although lacking the spectacular large mammals of the African savannas, the range of small to medium-sized species in this region is unparalleled, and surpasses even that of the vast, much more extensive Amazon plain stretching across the continent to the east. Furthermore, although some portions of the Tropical Andes are still in reasonably good condition, the majority of the area has been heavily impacted by human activities, and has been reduced to tiny fragments of its original extent. This combination of very high diversity and endemism in all groups of organisms, together with the very high levels of threat, makes the Tropical Andes the quintessential hotspot, placing this area at the very top of the list of global biodiversity conservation prioritiesâ (p. 69). Wilson (2002) writes: â œThe record for ants is 365 species from 10 hectares (25 acres) in a forest tract of the upper Peruvian Amazon. I have identified 43 species from the canopy of a single *tree* in the same region, approximately equal to the ant fauna of all the British Islesâ (p. 20). Terborgh (1999) writes: â œAs a repository of biodiversity, Manu National Park stands without peer. Its location on the western fringe of the Amazon basin puts it as the worldâ ™s biodiversity epicenter. The parkâ ™s biological value is further enhanced by its design, encompassing the entire watershed of the Manu River and its tributaries, from the 4,000-meter-high crest of the eastern Andes far out onto the lowland plain. By spanning such a broad range of environmental conditions, the Manu earns the distinction of holding more biodiversity than any other park in the world. Leading a litany of superlatives is a steadily expanding bird list of almost 1,000 species. (By contrast, only 650 species reside in all of North America north of Mexico.) In addition, more than 200 species of mammals, including 13 primate species, jaguars, pumas, ocelots, tapirs, capybaras, giant anteaters, and spectacled bears, live within the parkâ ™s boundaries. Reptiles and amphibians provide another showcase of diversity. Every year, the list of species known to occur in the park notches upward. The parkâ ™s lowlands can claim nearly 90 species of frogs and toads, a number surpassed only at one locality in Ecuador. Tree diversity in the Manuâ ™s forests ranges from 150 to 200 species per hectare. In just one month, a team of expert lepidopterists documented more than 1,300 butterfly species at a single lowland site. I could undoubtedly go on and on with such boasts had other groups of organisms been so thoroughly inventoriedâ (pp. 23, 25). Environmental News Network (2001) writes: â œA remote area of rain forest in northeastern Peru defined by three large rivers [Ucayali, Amazon and Yavari] appears to harbor more species of mammals than anywhere else on Earth. The mammal counts were published in two separate studies from different universities released at nearly the same timeâ ¦. Valqui and Voss [two scientists who have been taking inventory of the areaâ ™s mammals] both say this Amazon regionâ ™s high diversity is biologically rich because it is a vast, uninterrupted rain forest. Also, the rapid rise of mountains in the Andes between three million and eight million years ago created ridges that isolated animals, allowing them to evolve into distinct species. In addition, Valqui said, water running off the mountains produces richer soils in the western Amazon, allowing higher populations of all species and fewer extinctionsâ (pp. 1â “2). Gentry (1988) shows that 300 species of trees may be found in one hectare [2.47 acres] of

Peruvian rain forest. He writes: â œThe two plots from the everwet forests near Iquitos, Peru, are the most species-rich in the world, with roughly 300 species greater or equal to 10 cm diameter in single hectares; all of the Peruvian plots are among the most species-rich ever reported. Contrary to accepted opinion, upper Amazonian forest, and perhaps Central African ones, have as many or more tree species as comparable Asian forestsâ (p. 156). In comparison, there are roughly 250 tree species native to the entire European continent.

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p. 9: Soil Eating (â œGeophagyâ) as a Detoxification Strategy

Controlled laboratory experiments confirm the â œdetoxifying strategiesâ of macaws. Birds fed with plant alkaloids mixed with clay have 60 percent less alkaloids in their blood three hours after ingestion than birds fed without clayâ ”see Gilardi et al. (1999), who also show that macaws choose among clays. They write: â œâ ¦we found that preferred soils of parrots in Peru were generally smooth in texture with a sand content mean of less than 5 percent, which strongly argues that birds do not eat soil to enhance the mechanics of digestion. Rather, the parrots choose fine-grained soils with high clay content and correspondingly high cation exchange capacity and presumably can adequately masticate hard food items with their powerful and dexterous bills. Hence, geophagy in parrots invites alternative hypotheses on its function based on the structure and potential function of the clay itselfâ (pp. 912â “13). They add: â œIn summary, analyses of geophagy soils and experiments on captive parrots strongly reject the grit and pH-buffering hypotheses, and although minerals are released, our data suggests that minerals are unlikely to be the primary cause of the geophagy in parrots. From the in vitro adsorption trials, the effects on the toxicity of parrot food items, and the reduction of bioavailability of [the harmless plant alkaloid] quindine in captive birds, we conclude that geophagy can function to detoxify dietary toxins for vertebrate herbivores. The persistence of clay in the gastrointestinal tract may also be an important function of geophagy. Since detoxification is likely to occur in the lumen of the gut and the gastrointestinal mucosa is roughly similar among vertebrates, these two functions, dietary detoxification and cytoprotection, may well be universally applicable to all soil-eating animals including humans, nonhuman primates, ungulates, and other herbivores. Because of their structures, however, soils can, and likely do perform a variety of functions for vertebrate consumers. Given the complexities of plant chemistry, gastrointestinal physiology, and animal ecology, the causes of this phenomenon are likely to be multifactorialâ (p. 918). Diamond (1999) comments: â œPeruvian parrots behave like sophisticated human tourists and hunter-gatherers. Their preferred soils were found to have a much higher cation-exchange capacity than adjacent bands of rejected soilsâ ”because they are rich in the minerals smectite, kaolin and mica. In their capacity to bind quinine and tannic acids, the preferred soils surpass the pure mineral kaolinate and surpass or approach pure bentonite. Clearly, parrots would be well qualified for jobs as mining prospectorsâ   (p. 121). Engel (2002) writes about geophagy more broadly: â œIf there is one fact on which scientists researching geophagy agree, it is that the phenomenon has many benefits. The director of the Geophagy Research Unit at York University, William Mahaney, concludes that *all* geophagy is a form of self-medication. And the consumption of soil is so widespread and so inextricably linked to wild health that Timothy Johns suggests that geophagy could be the earliest form of medicine. Although some soils can be a source of nutrients (minerals and/or trace elements), the primary benefit of clay consumption is in countering dietary toxins. In essence, eating earth allows animals to deal with the effects of unavoidable toxinsâ   (pp. 69-70).

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p. 11: Glenn Shepardâ ™s Dream

See Shepard (1998).

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p. 14: False Alarm Calls by Bird Sentinels

Munn (1986b) writes: â œThe sentinel role has enabled *T. schistogynus* [the bluish-slate antshrike] and *L. versicolor* [the white-winged shrike-tanager] to establish a novel symbiotic relationship with other flock members. Both sentinel species rely on the insect-flushing abilities of other flock species for more than 85 percent of their food. Rarely do they steal arthropods directly from the bills of other birds. Rather, they sit in the center or beneath a group of actively foraging flock species and fly out or dive down after dropping arthropods flushed from hiding by the more active species. When a bird of another species begins to chase an arthropod that it has flushed out, the faster-flying, more aerobatic sentinel often catches the arthropod first. It is during these multi-bird aerial tumbles after arthropods that both species of sentinel give the same alarm call used when a hawk attacks or flies by. I interpret these calls as false alarm calls, presumably used by the sentinel to distract other birds and thereby to increase its own chance of capturing the arthropod. These aerial contests are over in less than a second, so even a slight hesitation by other birds increases the likelihood that the sentinel will reach the arthropod first. Using the following criteria, I classified 106 of 718 alarm calls as true or false: true if simultaneously I saw a hawk-like object fly by or if flock species subsequently alarmed and froze for several minutes, and false if the sentinel flew into the open after a falling arthropod while I simultaneously had a clear view of the entire region within 20 m of the bird and could thus eliminate the possibility of a passing hawk. Sentinels remained motionless on partially concealed perches when giving true alarms, whereas when giving false alarms, they flew with other birds into the open in pursuit of flushed arthropodsâ (p. 144). Dugatkin (1999) comments on Munnâ ™s observations: â œRemarkable as this story is, deceptive alarm callers are not all that smart. When giving a genuine alarm call, sentinels typically remain motionless on partly hidden perches. But, when emitting false alarm calls, alarmist birds fly out in the openâ ”a very dangerous thing to do, if a predator is truly in the area. Despite being intelligent enough to deceive others, they havenâ ™t really mastered the art of chicanery, for if they had, theyâ ™d not only voice a call but act the way scared birds act when danger is about. Of course, it is possible that natural selection has not favored such acting skills, since merely giving the call works so well. Yet that in many ways begs another question about cognitive complexity: why havenâ ™t the birds that keep getting bamboozled figured out that if an alarm caller doesnâ ™t head for the hills himself, then he is probably faking it? We simply donâ ™t know, nor has anybody even addressed the problemâ (p. 124). Munn (1986a) writes: â œWhile knowledge of the development of the use of alarm calls by the sentinel species might assist in clarifying the type of thinking, if any, which is employed by the bird when making the call, certain facts suggest that some amount of thinking is involved in sending and receiving the alarm call. That the sender thinks about what its call implies is suggested by one occasion in which a *Thamnomanes schistogynus* began to give the false alarm as it flew out after a falling insect that was being chased by another bird, but once it became clear that the other bird had captured the insect, the calling antshrike immediately graded its call into a wider-frequency nonalarm rattle call, which functions like a rallying call for other birds. The bird apparently realized that the alarm call was no longer appropriate and switched to the nonalarm call in mid-vocalization. Additionally, the fact that both sentinel species use the false alarm calls more frequently when feeding fledglings might suggest that they are â ˜savingâ ™ this trick for a situation in which they are genuinely desperate for extra food. The behavior of receivers suggests that they recognize that one potential meaning of the alarm calls is the approach of a predator. These birds are not simply startled by an alarm callâ ”rather, often they look in the direction of the call. This reaction is especially obvious when birds already in thick cover jerk their heads quickly and look in the direction of an alarm. This looking implies that alarm calls are interpreted as meaning something more like â ˜hawk!â ™ than like â ˜jumpâ ™â (p. 174).

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P. 15: CROW INTELLIGENCE

Savage (1995) writes: â œBut can a mere bird brain really cope with this intellectual challenge? How can birds learn and remember without an elaborate cerebral cortex? By the 1960s, neurologist Stanley Cobb had the answer. The avian brain, he discovered, is built on its own unique plan. Instead of relying on the cortex, birds have developed another part of the forebrain, the hyperstriatum (which mammals lack), as their chief organ of intelligence. The larger the hyperstriatum, the better birds fare on intelligence tests. Crows, ravens and magpies are all at the high end of both scales. And, as other investigators have since determined, corvids are also tops among birds for overall brain size. (Their brain-to-body ratio equals that of dolphins and nearly matches our own.) Whatâ ™s more, their large brains are packed tight with exceptionally large numbers of brain cellsâ (p. 29). Skutch (1996) writes: â œOrnithologists are sometimes asked which birds are most intelligent. An answer often given is crows, ravens and related birdsâ ”the corvids. These large, aggressive, opportunistic omnivores exhibit great behavioral flexibility by taking foods so diverse as fruits, insects, small living vertebrates, carrion, and much else. When removed from the nest before they are well feathered to be hand-raised, they become strongly attached to their foster parents, often regarding one as a mate. Their tameness recommends them for the intelligence tests that experimenters give them in laboratories, and they make relatively good scores. Their intelligence won them a place at the summit of the evolutionary tree in certain older systems of classification, although now, as in the most recent check-list of the American Ornithologistâ ™s Union, they are placed near the bottom of the Oscine passerines, with finches, weavers, and allied families at the top. The great difficulty of sharply separating learned or innovative behavior, on the one hand, and innate or genetically determined behavior, on the other, and the vast diversity of the lifestyles and activities of birds, make it impossible to decide which are most intelligentâ (pp. 120â “21).

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P. 15: Clarkâ ™s Nutcrackersâ ™ Memory of Caches

Kamil and Balda (1985) write: â œNutcrackers expend substantial amounts of time and energy during the late summer and fall harvesting seeds from pine cones, transporting them up to 22 km, and then burying the pine seeds in thousands of discrete caches. In a year of a heavy pine seed crop, a Clarkâ ™s nutcracker may store between 22,000 and 33,000 seeds, and a single Eurasian nutcracker between 86,000 and 100,000 seeds. These seeds are then recovered over the course of the next 11 months and form the bulk of the diet during the winter and during the breeding season. The nutrients and energy obtained from cached seeds allow the nutcracker to overwinter and breed early in the year in harsh alpine habitats where other foods are often rare to nonexistent. Field observations suggest that nutcrackers accurately find specific locations of hidden caches up to 11 months after making themâ (pp. 95â “96).

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P. 15: Scrub Jays with Foresight

Emery and Clayton (2001) write: â œTo our knowledge, this is the first experimental demonstration that a non-human animal can remember the social context of specific events, and adjust their present behavior to avoid potentially detrimental consequences in the future, in this case pilfering. To do this, scrub jays need experience of pilfering another birdâ ™s caches, but do not require experience of observing a conspecific hide food. They can recall specific past events, but the present results raise the possibility that they can also plan for the future. The jays seem to have transferred their previous experiences of being a pilferer to the current situation in which their own caches might be stolen. This may be a good candidate for knowledge attribution to conspecifics (seeing leads to knowing), use of this knowledge to influence subsequent behavior (re-caching in new locations) or even tactical deception. Mental time travel (episodic memory and future planning) and mental attribution were thought to be unique to humans. The cache recovery model presents a new way of addressing these issues in animalsâ (p. 445).

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p. 15: Pigeons Can Tell Van Gogh from Chagall

Watanabe (2001) writes: â œIn Experiment 1, pigeons were trained to discriminate between paintings by Van Gogh and Chagall. After training, the subjects were tested with different paintings by the same artists. The subjects showed generalization to these paintings. The subjects maintained their discriminative ability for black-and-white paintings and partially occluded paintings. When they were tested with mosaic paintings, the number of correct responses decreased, depending on the level of processing needed. In Experiment 2, human subjects were tested with the same paintings. The subjects showed generalization and decrement of correct responses depending on the degree of mosaic processing. These observations suggest that the visual cognitive function of pigeons is comparable to that of humansâ (p. 147).

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p. 15: Songbirds Learn to Sing

Specter (2001) writes: â œCanaries live, on average, for ten years, cover a wide octave range, and sing for several reasons: to announce themselves, to claim territory, and to scare away other males when they look for a mate. (Females rarely sing.) As Charles Darwin noted, a songbirdâ ™s early, rudimentary attempts at vocalizationâ ”called subsongâ ”have a lot in common with the babbling of a human infant. By the time canaries are eight months old, though, they sing like adults, and their habits never vary: they sing throughout the breeding season, in the spring, and then, during the summer molting season, they shed the songs as if they were feathers. The next spring, the same birds will turn up with an entirely new repertoire.â (p. 42). Catchpole and Slater (1995) write: â œLearning has been found to have a role in song development in every species of songbird studied to date. The songbirds, or oscines, are a subdivision of the passerines, comprising some 4000 of the 9000 or so species of birds known to existâ (p. 66). Skutch (1996) writes: â œA large segment of avian behavior, especially its more complex forms, is perfected by learning and experience building upon the innate foundation that we call instinct. Starting with an imperfect hereditary pattern of its speciesâ ™ song, a songbird improves his performance by listening to his elders. Birds appear to have an innate pattern of their nests; but at least the more elaborate of them, such as those of certain African weavers, are not finished without practice. Many studies have demonstrated that experience makes birds more efficient parents; pairs nesting for the first time rear fewer young than do older breeders. Although the impulse to fly in a certain direction is innate in at least some migratory birds, the competent navigation that many display by commuting annually between familiar winter and breeding territories, separated by thousands of miles, is not attained without observation, learning, and experience. These are only a few of birdsâ ™ activities in which learning complements innate tendenciesâ (p. 121).

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P. 15: BIRDS PRACTICE SINGING IN THEIR DREAMS

Dave and Margoliash (2000) write: â œSongbirds learn a correspondence between vocal-motor output and auditory feedback during development. For neurons in a motor cortex analog of adult zebra finches, we show that the timing and structure of activity elicited by the playback of song during sleep matches activity during daytime singingâ ¦Our observation of neuronal replay of sensorimotor patterns during sleep is consistent with data from hippocampal studies suggesting that sleep is important for the consolidation of neuronal temporal codes for spatial memory. The fundamental prediction of our model is that birdsong learning depends on sleep or other off-line computationsâ (pp. 812, 815). On neurogenesis in the human brain, see Eriksson et al. (1998).

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P. 16: BIRD BRAINS

Pepperberg (1999) writes: â œNeurobiological studies on parrots date back to the beginning of the twentieth century. Researchers at the time suggested that mammalian standards for correlations between brain structureâ ”absolute brain size and particularly relative cortical sizeâ ”and intelligence might not hold for birds. Kalisher (1901), using what were clearly rather primitive techniques, found that striatal rather than cortical areas might be involved in avian intelligence. The metaphor I like to use involves looking at avian and mammalian brains as early Macintosh versus IBM-style computers. These different information-processing machines use the same wires, and when you enter the same data into their programs you get the same resultsâ ”but the wires are organized differently and you must use programs designed for their differently configured systems. Although the work of the early researchers was essentially ignored for several decades, later elegant experiments drew more convincing parallels between avian learning and memory and these striatal areasâ ¦Of particular interest was research that suggested a link between striatal development and â ˜intelligence.â ™ On studies of reversal learning, set learning, oddity problems, number-related problems, and insight detour problems, birds with the greatest striatal developmentâ ”such as crows, parrots, and mynahsâ ”performed more accurately than birds with lesser striatal developmentâ ”such as pigeons and domestic fowlâ ”and were often superior to some monkeys. Moreover, lesions in these areas appeared to interfere with learning. Parrots had also performed at high levels on problems involving simple labeling and intermodal associations, and Grey parrots had demonstrated the ability to respond as accurately on new problems as on related training problems. This ability to transfer information between problems is generally considered evidence for advanced cognitive capacities. Such findings suggested that birds did not need an extensive cerebral cortex to perform complex cognitive tasks, and that the extent of avian intelligence, based primarily on studies on pigeons, might be markedly underratedâ (pp. 9â “10).

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P. 16: SHAMANS SPEAK â œTHE LANGUAGE OF THE BIRDSâ

Eliade (1964) writes: â œAll over the world learning the language of animals, especially of birds, is equivalent to knowing the secrets of nature and hence to being able to prophesy. Bird language is usually learned by eating snake or some other reputedly magical animal. These animals can reveal the secrets of the future because they are thought to be receptacles for the souls of the dead or epiphanies of the gods. Learning their language, imitating their voice, is equivalent to ability to communicate with the beyond and the heavens. We shall again come upon this same identification with an animal, especially a bird, when we discuss the shamanâ ™s costume and magical flight. Birds are psychopomps. Becoming a bird oneself or being accompanied by a bird indicates the capacity, while still alive, to undertake the ecstatic journey to the sky and beyondâ (p. 98). Guss (1985) writes: â œAccompanied by drum or rattle, by drugs, costume, and dance, the shaman enters his trance through the power of his words and once there receives the special message he has set out to learn. This messageâ ”special in both form and contentâ ”is delivered in another language, the secret, esoteric one that spirits and animals use in their own world. This is the language of transformation and Magic Words, the language of the unconscious and the underworld, the one that shamans speak to one another and refer to as the â ˜Language of the Birdsâ ™â (p. xi). Frazer (1888) writes: â œThe reason why the serpent is especially supposed to impart a knowledge of the language of the birds appears from a folk-lore conception of the origin of serpents. According to Democritus as reported by Pliny, serpents are generated from the mixed blood of diverse birds. This explains why serpents should understand the language of birds; they do so, because they are blood relations of birds, having the blood of birds in their veinsâ (pp. 180â “81).

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P. 17: The Owner of Animals as Protector of all Species

Reichel-Dolmatoff (1976) writes, referring to the Desana of the Colombian Amazon: â œThe Desana believe in supernatural personifications that are closely associated with the animal world, and that are often described as the protectors and representatives of the local fauna. The most prominent of these beings is the Master of Animals, called *vai-mahsÃ«,* â ˜Animal-Person,â ™ who is imagined as an anthropomorphic being, a phallic dwarf, who lives among the animals and is their constant companion and guardian. He is not associated with a certain species, but *all* animals are thought to stand under his care. All this is imagined as happening in a dimension of an Otherworld wherein animals are socially organized and behave very much like humans: they talk, sing, dance and otherwise go about their daily routine like rational beings. The spirit-forms of these animals are supposed to reside inside isolated rocky hills that rise here and there in the forest, and these â ˜houses,â ™ as they are called, are avoided by peopleâ ¦*Vai-mahsÃ«* is thus imagined to exist in many personifications: as a Master of Game Animals, a Master of Fish and, in quite general terms, as an overall spirit-protector of all species, or indeed of all nature. Within one central concept of â ˜Master of Animals,â ™ there are thus many, and quite often the term is pluralized as *vai-mahsa* and thus reference is made to groups of â ˜mastersâ ™ or to their individual familiesâ (p. 161). Reichel-Dolmatoff (1978) writes: â œ*Vai-mahsÃ«,* isâ ¦first and foremost a gamekeeper who protects his wards, and who constantly has to admonish the hunters and fishermen not to exceed themselves in the pursuit of their preyâ (p. 262).

Chapter 2

P. 19: Rain Forests Have Poor Soils

The heat and humidity prevailing under the canopy of rain forests speed the breakdown of organic matter so that nutrients are quickly recycled by the vegetation. This means that biological wealth does not have time to accumulate in the soil, and therefore that clear-cutting rain forests is a recipe for desertification. Davis (1998) writes: â œForests have two major strategies for preserving the nutrient load of the ecosystem. In the temperate zone, with the periodicity of the seasons and the resultant accumulation of rich organic debris, the biological wealth is in the soil itself. In the tropics it is completely different. With constant high humidity and annual temperatures hovering around 80 degrees Fahrenheit (27 degrees Celsius), bacteria and microorganisms break down plant matter virtually as soon as the leaves hit the forest floor. Ninety percent of the root tips in a tropical forest may be found in the top ten centimeters of earth. Vital nutrients are immediately recycled into the vegetation. The wealth of this ecosystem is the living forest itself, an exceedingly complex mosaic of thousands of interacting and interdependent living organisms. It is a castle of immense biological sophistication built quite literally on a foundation of sand. Removing this canopy sets in motion a chain reaction of destruction with cataclysmic consequences. Temperatures increase dramatically, relative humidity falls, rates of evapotranspiration drop precipitously, and the mycorrhizal mats that interlace the roots of forest trees, enhancing their ability to absorb nutrients, dry up and die. With the cushion of vegetation gone, torrential rains cause erosion which leads to further loss of nutrients and chemical changes in the soil itself. In certain deforested areas of the Amazon the precipitation of iron oxides in leached exposed soils has resulted in the deposition of miles upon miles of lateritic clays, a rocklike pavement of red earth in which not even a weed will growâ (p. 111).

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p. 22: Communicating with Plants and Animals Through Song

Descola (1994) writes about concepts of nature among the Achuar people of Ecuador and Peru: â œIf, in spite of everything, natureâ ™s beings manage to communicate among themselves and with humans, it is because they have other means of making themselves understood than by emitting sounds that can be heard by the ear. In effect, intersubjectivity can be expressed by speech from the soul, which transcends all linguistic barriers and transforms every plant and animal into a subject capable of producing meaning. Depending on the way in which communication is to be established, this soul speech can take any number of forms. Normally humans speak to plants and animals by means of incantations, which are supposed to go straight to the heart of whoever they are addressed to. Although they are formulated in ordinary language, these songs can be understood by all of natureâ ™s beingsâ ¦. This sort of sung metalanguage is also used by the various species of animals and plants to communicate with each other, thus overcoming the solipsistic curse of separate languages. But, although humans in their waking state are able to send messages to plants and animals, they are not able to intercept either the information these beings exchange or the answers they send back. For a true interlocutory relation to be established between natureâ ™s beings and human beings, their respective souls must leave their bodies and free themselves of the material constraints of speech by which they are ordinarily bound. Soul journeys occur mainly during dreams or trances brought on by hallucinogenic drinks made from *Datura* (*maikiua*) or *Banisteriopsis* (*natem*). Shamans are particularly adept at controlling the wanderings of their conscious double, as they have a great deal of practical experience in sending out their souls. But this is not an exclusive prerogative of shamans, and anyone, man, woman, or child, under certain circumstances, is capable of sending his soul beyond the narrow confines of the body in order to dialogue directly with the double of another of natureâ ™s beings, be it human, plant, animal, or supernatural spiritâ (pp. 99â “100).

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P. 22: The Owner of Animals as Jaguar and Transformer

Reichel-Dolmatoff (1978) writes about the master of animals as understood by the Desana people of the Colombian Amazon: â œ*Vai-mahsÃ«* will appear to many people in many disguisesâ ¦. Assuming the functions of a fertilizing rain god, he is imagined as hurling his thunderbolts of white quartz splinters or, rather, he turns himself into a bolt that suddenly strikes a hill, a tree, or even a house. People say: *vai-mahsÃ« mohÃ³ yuriÃ¡ya,* â ˜*vai-mahsÃ«*â ”-let fallâ ”his weaponâ ™; or they might say: *yee mohÃ³ yuriÃ¡ya,* the word *yee* standing for either jaguar or shaman. In fact, the Master of Animals is both; in jaguar form he dominates all other animals, and among his creatures he is the wise shaman, the protector, the mediator between the hunter and his prey. He might also manifest himself in a great storm, or as a cock of the rock displaying his bright yellow plumage, or as a lizard, a fish, or a cacique bird.â (pp. 262â “63).

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P. 26: Intelligent Design and the Designer

Dembski (1999) writes in his book *Intelligent Design: The Bridge between Science and Theology:* â œTo say that God through the divine *Logos* acts as an intelligent agent to create the world is only half the story. Yes, there is a deep and fundamental connection between God as divine *Logos* and God as intelligent agentâ ”indeed the very words *logos* and *intelligence* derive from the same Indo-European root. The world, however, is more than simply the product of an intelligent agent. In addition, the world is intelligibleâ ¦Human language is a divine gift for helping us to understand the world and by understanding the world to understand God himself. This is not to say that we ever comprehend God as in achieving fixed, final and exhaustive knowledge of God. But human language does enable us to express accurate claims about God and the world. It is vitally important for the Christian to understand this point. Human language is not an evolutionary refinement of grunts and stammers formerly uttered by some putative apelike ancestors. We are creatures made in the divine image. Human language is therefore a divine gift that mirrors the divine *Logos*â (pp. 229â “30). Behe (2001) writes: â œA theory of intelligent design, however, holds implicit that there is a designer capable of planning and executing the phenomenal intricacies of life on earth. Although there are, at least in theory, some exotic candidates for the role of designer that might be compatible with materialist philosophy (such as space aliens or time travelers), few people will be convinced by these and will conclude that the designer is beyond nature. Many scientists are unable or unwilling to accept such a designer because that goes against their prior commitment to materialism, or at least to a functional materialism in the course of their work. Nonetheless, I remain optimistic that the scientific community will eventually accept intelligent design, even if the acceptance is discreet and muted. The reason for optimism is the advance of science itself, which almost every day discovers new intricacies in nature, fresh reasons for recognizing the design inherent in life and the universeâ (pp. 100â “1).

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P. 26: Atheism Is Theism Denied

Gray (2002) writes: â œUnbelief is a move in a game whose rules are set by believers. To deny the existence of God is to accept the categories of monotheism. As these categories fall into disuse, unbelief becomes uninteresting, and soon it is meaningless. Atheists say they want a secular world, but a world defined by the absence of the Christiansâ ™ god is still a Christian world. Secularism is like chastity, a condition defined by what it denies. If atheism has a future, it can only be in a Christian revival; but in fact Christianity and atheism are declining togetherâ (p. 126â “27).

CHAPTER 3

P. 31: Shamanism Is Transforming

Townsley (2001) comments on the waning of shamanism among indigenous people: â œClearly the central momentum of the last few hundred years of history has been *away* from indigenous communities, their worldviews, and the things like shamanism that are part and parcel of them. As we all know, in many parts of the world these have been violently trampled under foot. In others, where indigenous people are trying hard to join what they perceive to be the exciting world of the future, shamanism begins to look like old-fashioned hocus-pocus and is quietly forgotten. In one way or another, the arrival of modernity and its paraphernalia is usually the death knell of these different, primitive, animist, whatever you want to call them, worldviews. The interesting reflux of that central current of history is that just as â ˜primitiveâ ™ worldviews die out in the hinterlands of the new global system, they take root at its center. To the urban middle classes, already saturated with modernityâ ™s paraphernalia and bored with the world bled of meanings they seem to entrain, shamanism, voodoo, witchcraft, all things primitive, suddenly seem extremely appealing. It is an interesting historical crisscross. To the so-called primitive, marginalized, and usually powerless, the promise of the modern is *things,* ease and security. To the so-called modern, the promise of the primitive is the one thing he or she lacksâ ”*meaning*. This primitive rush for the modern and the modern rush for the primitive is one of the weird but well-recognized features of the current cultural landscape of our world. Many of us spend our lives traversing itâ (p. 50). See also Leclerc (2003).

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P. 33: AMAZONIANS VIEW NATURE RELATED TO HUMANS

Across the Western Amazon indigenous people commonly consider plants and animals as persons living in societies of their own and endowed with knowledge, agency, emotions, intentions, and the capacity to exchange messages with themselves and with members of other species, including humans. Descola (1999) writes: â œAmazonian Indiansâ ¦. have integrated the environment into their social life in such a way that humans and non-humans are treated on equal grounds. Most of the regionâ ™s cosmologies do not operate clear-cut distinctions between nature and society, but confer the main attributes of humanity to a good number of plants and animalsâ (p. 220). Arhem (1996) writes about the Makuna of the Colombian Amazon: â œThe Makuna describe animals as â ˜persons.â ™ Game animals and fish are endowed with knowledge, agency and other human attributes. They are said to live in malocas in the forest and the rivers, in saltlicks, hills and rapids. When animals roam in the forest or swim in the rivers they appear as fish and game, but as they enter their houses they discard their animal guises, don their feather crowns and ritual ornaments, and turn into â ˜peopleâ ™â ¦. Indeed, each species or community of animals is said to have its own â ˜-culture,â ™ its knowledge, customs and goods by means of which it sustains itself as a distinct class of beingsâ (p. 190). He adds: â œThe Makuna stress the continuity between nature and society, and ultimately the essential unity of all life, as manifest in the notions of *masa*â ”the â ˜humannessâ ™ of all beingsâ ”and *he*â ”the undifferentiated, transcendental reality beyond all physical differentiation. Human predationâ ”hunting, fishing, and gatheringâ ”is construed as exchange, and killing for food is represented as a generative act through which death is harnessed for the renewal of life. Such an ideology has powerful implications for human actions. Animal â ˜othersâ ™ are treated as â ˜equalsâ ™ and â ˜persons,â ™ parties to a moral pact governing relations within human society as well as the grander society of all beings. Rather than proclaiming the supremacy of humankind over other life forms, thus legitimizing human exploitation of nature, Makuna eco-cosmology emphasizes manâ ™s responsibility towards the environment and the interdependence of nature and society. Human life is geared to a single, fundamental and socially valued goal: to maintain and reproduce the interconnected totality of beings which constitute the living world; â ˜to maintain the world,â ™ as the Makuna say. In fact, this cosmonomic responsibility towards the wholeâ ”and the accompanying shamanic knowledgeâ ”is, according to the Makuna, the hallmark of humanityâ (pp. 200â “1).

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p. 36: A Book by the Peruvian Amazonâ ™s Indigenous People

This book, *El Ojo Verde: Cosmovisiones AmazÃ³nicos (The Green Eye: Amazonian Cosmovisions)* is a treasureâ ”see AIDESEP (2000) and www.perucultural.org.pe.

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p. 37: Shamans Are Transformers

Canetti (1960) writes: â œThe capacity of humans to transform/ metamorphose themselves, which has given them so much power over other creatures, has hardly been studied and understood yet. It is one of the greatest enigmas: each person has it, and uses it, and everyone considers it perfectly natural. But few people recognize that they owe it the best of who they areâ (p. 373). The quote in the main text is from Reichel-Dolmatoff (1987, p. 10).

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p. 37: Lascauxâ ™s Bird-Headed Man

Campbell (1959) writes: â œMoreover, there is another uncanny painting, even more suggestive of the mystery of this Stone Age cathedral of hunting magic, at the bottom of a deep natural shaft or crypt, below the main level of the floor of the caveâ ”a most difficult and awkward place to reach. Down there a large bison bull, eviscerated by a spear that has transfixed its anus and emerged through its sexual organ, stands before a prostrate man. The latter (the only crudely drawn figure, and the only human figure in the cave) is rapt in a shamanisticn tranceâ ¦. The man wears a bird mask and has birdlike instead of human hands. He is certainly a shaman, the bird costume and bird transformation being characteristic, as we have already seen, of the lore of shamanism to this day throughout Siberia and North Americaâ (pp. 300â “1). Davenport and Jochim (1988) write regarding the bird-headed manâ ™s four-fingered hands: â œFour is the precise number of digits that a bird has. The replacement of each human hand with a four-fingered birdâ ™s foot was a deliberate and, indeed, sophisticated ploy of the artist to make the image more bird-likeâ ¦One is constrained to wonder what the reaction of the artist would have been if told that fourteen or more millennia after his death, many authorities on his art would have so lost contact with the natural world as to be unaware of the significance of his putting four â ˜fingersâ ™ on each hand. The artist has, in fact, portrayed the humanoid as half bird and half man, bird from then waist up and man from the waist downâ (p. 560). Giedion (1957) writes: â œI share the opinion of S. Blanc, of Les Eyzies, former Inspector of Historic Monuments, that this bird man is in fact standing upright at the moment of supreme exaltation. One arm, with a four-fingered hand, points toward the bird on a pole, the other points toward the collapsing bison with its spilling entrails. The man is ithyphallic and bears signs of the highest excitement and concentration of his powersâ ¦. When I first visited the caverns in 1949, I asked a local photographer to take a picture of the bird man from the ground of the â ˜well,â ™ shooting on a plane without tilting the camera or using any artificial expedients. The bird man stood upright in all his strength. The scene is placed in a ritually important position close to the end of the cavern. It is difficult to reach, being below the normal level of the cavern and separated from it by a small rock wall. If one looks down into the â ˜wellâ ™ from this position, the figure again stands uprightâ (p. 508).

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p. 37: Trois FrÃˆres â œSorcererâ

BÃ©gouÃ«n (1929) writes: â œHere we see an amazing masked human figure with a long beard, the eyes of an owl, the antlers of a stag, the ears of a wolf, the claws of a lion and the tail of a horse. It is engraved and outlined in black paint, about ten feet from the ground, in a nook most difficult of access in a small round chamber known as the Sanctuary. It seems to dominate and preside over all the hundreds of other creatures, of thirteen different species, engraved and drawn on the walls below. It is the supreme mystery of the cave. Can it be some weird deity of those primitive people? Perhaps rather it is the Arch-Sorcerer who has taken unto himself the diverse attributes of the beasts he enchants, a character personified even in our own day by the Shaman of the primitive tribes of Siberiaâ (p. 17).

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P. 38: Chauvet Cave Feline Bison Woman

Chauvet et al. (1996) write: âœEveryone knows that humans are extremely rare in Palaeolithic art. Chauvet cave is no exception, since not one image of a complete human figure has been found there yet. There are only some segments of the body and one composite beingâ¦a black creature, upright and leaning slightly forward: the top of its body is that of a bison, and the bottom that of a human, with the two legs well indicatedâ (p. 110). The paintings at the Chauvet cave have been carbon-dated on the basis of 28 samples, which is more than any other prehistoric cave, the great majority of which belong to a period situated between 30,000 and 33,000 years ago (see Clottes et al. 2001, pp. 32â“33).

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P. 38: Shamans and Chimera Imagery in Prehistory

Clottes and Lewis-Williams (1998) write in their book *The Shamans of Prehistory: Trance and Magic in the Painted Caves:* âœâ¦the images that seem to represent half-human, half-animal beings, though comparatively rare, were clearly highly significant in Upper Paleolithic times. The placing of the so-called Sorcerer in a commanding position high above the Sanctuary in Les Trois-FrÃ¨res is particularly strikingâ¦. Most researchers have interpreted these and other images as disguised or costumed â˜sorcerersâ™; some writers have compared them with Witsenâ™s [eigthteenth-century] picture of a Siberian shaman. The general shamanic context of the art, however, suggests other possibilities. They may be images of shamans partially transformed, in their Stage Three hallucinations, into animals, as are comparable southern African and other shamanic images. On the other hand, they may be manifestations of a Lord of the Animals. People in many shamanic societies believe in a Lord of the Animals who has control of animals, sees to their conservation, and, under certain conditions that frequently involve propitiatory rituals, releases them to hunters. Either way, these images of transformation are clearly part of a shamanic belief system. They belong to the third stage of hallucination and to the lower level of the shamanic cosmos.â Yet the shamanic nature of prehistoric paintings is indeterminate. As Patte (1960) writes: âœIt is true that one can find several drawings which shamanism can account for; there is the staff with a bird on it that the Lascaux stick-man has abandoned at his side; similar staffs and birds play a big part in shamanism; but Horus too had a scepter with the head of a hare which resembled him considerably; and there is the â˜Sorcererâ™ of Trois-FrÃ¨res with his stag antlers, who reminds one of the costumed shamans found in several contemporary populations; but antler headdresses are also found outside of shaman countryâ¦. The essence of shamanism consists of spiritual flights by the shaman, who has entered into trance, and who is looking either for souls, or for information or favors from the master or mistress of animals regarding successful hunting or fishing or the arrival of rain; to do this, the shaman requires the help of a spirit. And, of all this, one can know nothingâ ¦Shamanism and totemism are phenomena much too particular to be affirmed in the absence of written dataâ (p. 172â "73). Vitebsky (1995) writes: â œThe ideas surrounding shamans are so complex and subtle that it takes all the efforts of anthropologists working among living people to discover them, and even then there are many dangers of misunderstanding. It is possible that Paleolithic hunters had shamans in their communities, but the theory cannot be proved. It seems unquestionable that, until the development of agriculture, all human societies were based on hunting and in recent history shamanism has had a particularly strong link with the hunting way of life. This is not, however, a simple and exclusive connectionâ (p. 29). Bahn and Vertut (1998) write: â œThe realization that motifs and motives in Paleolithic art are not easily recognizable has meant researchers have found it ever harder to move beyond detailed descriptions and well-meant speculations. What it comes down to, basically, is whether one is content to work with the art as a body of markings that cannot be read, or whether one wants to have stories made up about it!â (p. 21).

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p. 38: Hybrid Signs with a Multiplicity of Meanings

Giedion (1957) writes: â œMasks and hybrid figures have this in common: it is impossible to determine them with any exactitude. It is impossible to come near to their meaning without bringing in the essential factor of indetermination. Indetermination between the real and the imaginary constitutes their rightful being, their rightful nature. It is related to the hovering indefinite forms which appear so often in primeval art and are a means of giving expression to relations with the supernatural. With the symbols, multiplicity of meanings hindered an understanding of their significance. With the hybrid figures, on the contrary, it is the very factor of indetermination which gives the key to a comprehension of primeval religious concepts. Primeval man remained enveloped in a marvelous unity of existence that embraced both the sacred and the profaneâ (p. 511â "12).

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p. 38: Kinship with Nature Established by Science

Wilson (1993) writes: â œ*Other species are our kin.* This statement is literally true in evolutionary time. All higher eukaryotic organisms, from flowering plants to insects to humanity itself, are thought to have descended from a single ancestral population that lived about 1.8 billion years ago. Single-celled eukaryotes and bacteria are linked by still more remote ancestors. All this distant kinship is stamped by a common genetic code and elementary features of cell structure. Humanity did not soft-land into the teeming biosphere like an alien from another planet. We arose from other organisms already hereâ (p. 39, original italics). Wade (1998) writes: â œMice are a lot like people. It took the advance of science to prove this humbling truth. Generations of men have prided themselves on being martial, mighty, menacing, magnificentâ ”in a word, unmouselike. Geneticists now know better. The instructions to develop and operate a human require three billion chemical letters of DNA, the genetic material. But mice, too, have three billion letters of DNA in each of their cells, as if their design plan were every bit as sophisticated. For every 100 human genes, 97 or more have counterparts in the mouse, and these mouse genes, in the language of DNA, are spelled very similarly to the human genes. Indeed, the common ancestor of mice and humans lived only 75 million years ago. This genetic cousinship makes mice ideal for medical studies. At every level, from gene to cell to physiology, they work the same way humans doâ (p. WK 5). Mouse Genome Sequencing Consortium (2002), which revealed the complete sequence of the mouse genome, writes: â œThe proportion of mouse genes without any homologue currently detectable in the human genome (and vice versa) seems to be less than 1%â (p. 521).

CHAPTER 4

P. 41: CHIMPANZEES WITH CULTURE

Whiten and Boesch (2001) write: â œHumankindâ ™s nearest relative is even closer than we thought: chimpanzees display remarkable behaviors that can only be described as social customs passed on from generation to generationâ ¦During the past two years, an unprecedented scientific collaboration, involving every major research group studying chimpanzees, has documented a multitude of distinct cultural patterns extending across Africa, in actions ranging from the animalsâ ™ use of tools to their forms of communication and social customs. This emerging picture of chimpanzees not only affects how we think of these amazing creatures but also alters human beingsâ ™ conception of our own uniqueness and hints at very ancient foundations for humankindâ ™s extraordinary capacity for cultureâ (pp. 49, 50â “51).

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P. 42: DOLPHINS RECOGNIZE THEMSELVES IN MIRRORS

In an experiment conducted by Reiss and Marino (2001), two bottlenose dolphins living in captivity in the New York Aquarium were marked in black ink on parts of their bodies that they cannot usually see. They were also â œsham-markedâ with water rather than ink.

Both dolphins were accustomed to living in a tank equipped with a mirror. In separate trials, each animal repeatedly swam straight to the mirror to investigate the place where it had been marked, often twisting and turning to expose the proper spot, on the underbelly, above the pectoral fin or behind the ear. They also spent considerably more time examining marked places than sham-marked ones. And they showed no interest in marks on other dolphins. Until recently, scientists thought that only great apes and humans could recognize themselves in mirrors. This ability, which is considered to be a sign of self-awareness, was thought to be an exclusivity of â œhigher primates.â But these dolphins, who last shared a common ancestor with us 70 million years ago, seem to have developed self-awareness on their own.

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p. 42: Crows Build Standardized Tools

Hunt (1996) reported that a breed of small crows living in South Pacific rain forests manufacture tools with standardized hooks and toothed probes to help in their search for worms and insects hidden in holes. To make a hooked tool, the crows use their beaks to nip twigs away from a branch just at the point of intersection with another twig. When done carefully, this creates a small hook at the base of the twig. Hunt writes: â œCrow tool manufacture had three features new to tool use in free-living nonhumans, and that only first appeared in early human tool-using cultures after the Lower Paleolithic: a high degree of standardization, distinctly discrete tool types with definite imposition of form in tool shaping, and the use of hooksâ (p. 251). Hunt comments on his research: â œThere are many intriguing questions that remain to be answered about crowsâ ™ tool behavior. Most important would be whether or not they mostly learn or genetically inherit the know-how to make and use tools. Without knowing that it is difficult to say anything about their intelligence, although one could guess that these crows have the capability to be as clever as crows in generalâ (quoted in Davies 2002: 2â “3).

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p. 42: Vampire Bats Share Food

See Wilkinson (1984). Kennedy (2002) says: â œVampire bats nest in colonial roosts, and they go out at night hunting for prey. A sleeping dog, or livestock, or a beautiful woman. And itâ ™s quite obvious that this kind of predation doesnâ ™t always meet with success. I mean you donâ ™t find a sleeping dog just everywhere. Sometimes some bats score and other bats donâ ™t score. And a zoologist has studied now quite carefully the behavior of vampires who have been individually banded, so they can be distinguished as individuals within the colony, and watched them over long periods of time. And what turns out is that vampire bats, when they come home with a large blood meal, are apt to share it around. Thereâ ™s more than I can use, so please have someâ ”you have some, too. And he kept careful track of who the sharees are, and how the sharers treat them. And it turns outâ ”like humans playing iterated prisonersâ ™ dilemma games, they reward individuals that have shared with them earlier, just as in tit for tatâ (p. 6).

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p. 42: Alex the African Grey Parrot

See Pepperberg (1999). Stories on Alex appeared among others in *Scientific American* (see Mukerjee 1996) and the *New York Times* (see Smith 1999).

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p. 42: Ants Cultivate Mushrooms with Antibiotics

See â œFungus-growing ants use antibiotic-producing bacteria to control garden parasites,â by Currie et al. (1999). Schultz (1999) comments: â œLike the parallels between ant and human agriculture, understanding this use of antibiotics by ants could be directly relevant to human survivalâ ¦. Given that rapidly evolving pathogen resistance seems to be outpacing human antibiotic development, one might ask how the attine antibiotics have remained effective against the fungus-garden pathogens for such a long timeâ (p. 748). Wade (1999) comments: â œEven now, the ants are accomplishing two feats beyond the powers of human technology. The leaf-cutters are growing a monocultural crop year after year without disaster, and they are using an antibiotic apparently so wisely and prudently that, unlike people, they are not provoking antibiotic resistance in the target pathogenâ (p. D4). Colonies of some leaf-cutter species have the collective biomass of an adult cow, and they cut a cowâ ™s daily requirement of fresh vegetation. Leaf-cutter ants bring about 15 percent of the tropical forestsâ ™ vegetation into their nests.

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p. 43: Definitions of Intelligence

Stern (1999) writes: â œDifferent cultures and sub-cultures vary in the emphasis placed upon various expressions of intelligence. The skills and behaviors that are valued and encouraged in one society may be quite different from those valued and encouraged in anotherâ (p. 504). Franklin (1995) writes: â œBefore trying to define *artificial* intelligence, we thought it prudent first to say what we meant by *intelligence.* After almost two years of wrangling, we gave it up as hopelessâ (pp. 187â “88). For the quotes in the main text, see Gardner 1999 (pp. 19, 33â “34, 88, 94) and Stern 1999 (pp. 504, 506).

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P. 44: MONOD AND THE SCIENTIFIC METHOD

Monod (1971) writes: â œThe cornerstone of the scientific method is the postulate that nature is objective. In other words, the *systematic* denial that â ˜trueâ ™ knowledge can be reached by interpreting phenomena in terms of final causesâ ”that is to say, of â ˜purposeâ ™â ¦. This pure postulate is impossible to demonstrate, for it is obviously impossible to imagine an experiment proving the *nonexistence* anywhere in nature of a purpose, or a pursued end. But the postulate of objectivity is consubstantial with science, and has guided the whole of its prodigious development for three centuries. It is impossible to escape it, even provisionally or in a limited area, without departing from the domain of science itselfâ (original italics, pp. 30â “31).

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P. 45: MECHANICAL BEES

The quote is from Monod (1971, p. 18). The quote by Donald Griffin is from an interview by Vines (2001, p. 51).

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P. 45: CHANGING MENTALITIES IN SCIENCE

The quote is from Kennedy (2002, p. 7).

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P. 46: BACON AND ANTHROPOMORPHISM

Bacon (1960, orig. 1620) writes: â œâ ¦although the most general principles in nature ought to be held merely positive, as they are discovered, and cannot with truth be referred to a cause, nevertheless the human understanding being unable to rest still seeks something prior in the order of nature. And then it is that in struggling toward that which is further off it falls back upon that which is nearer at hand, namely, on final causes, which have relation clearly to the nature of man rather than to the nature of the universe; and from this source have strangely defiled philosophyâ (pp. 51â “52). Levy (2001) writes: â œAmong those who study animal behavior, anthropomorphism is generally considered a cardinal sin. That helps explain why they havenâ ™t expressed much interest in personality up until nowâ (p. 35). Why is anthropomorphic language so prevalent in science if it is so contrary to the scientific method? Scientists have given a problematic answer to this question. They say they use everyday language â œfor the simple reason that it is our everyday language and therefore readily understood,â whereas among themselves they believe they are using it â œin a purely metaphorical senseâ (see Kennedy 1992, p. 14). In other words, they take the liberty of using subjective language that they do not really mean so as to be comprehensible. So Richard Dawkins explains in his book *The Selfish Gene* that his anthropomorphic language is not to be taken at face value: â œIf we allow ourselves the license of talking about genes as if they had conscious aims, always reassuring ourselves that we could translate our sloppy language into respectable terms if we wanted to, we can ask the question, what is a selfish gene trying to do? It is trying to get more numerous in the gene poolâ (1976, p. 88). But there are problems with the notion of â œrespectable,â or â œobjective,â or â œneutralâ language. First and foremost, objective description can never be free from the knowing subject, because this would suppose that individual scientists could somehow leap outside of themselves and determine accurately what is subjective and what is objective. But no one can attain a point of view that lacks a point of view. A truly neutral language does not exist. In particular discussions about anthropomorphism are not objective, but culturally dependent.

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p. 46: Descartes

The quote is from Descartes (1997, orig. 1631, pp. 107, 108â “9).

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p. 48: Hume, Locke and Schopenhauer

David Hume wrote in *A Treatise of Human Nature* (1978, orig. 1739): â œâ ™Tis from the resemblance of the external actions of animals to those we ourselves perform, that we judge their internal likewise to resemble ours; and the same principle of reasoning, carryâ ™d one step farther, will make us conclude that since our internal actions resemble each other, the causes, from which they are derivâ ™d, must also be resembling. When any hypothesis, therefore, is advancâ ™d to explain a mental operation, which is common to men and beasts, we must apply the same hypothesis to bothâ (pp. 176â “77). John Locke wrote in *An essay concerning human understanding* (1975, orig. 1689): â œ*Perception,* I believe, is, in some degree, *in all sorts of Animals;* though in some, possibly, the Avenues, provided by Nature for the reception of Sensations are so few, and the Perception, they are received with, so obscure and dull, that it comes extremely short of the quickness and variety of Sensations, which is in other Animals: but yet it is sufficient for, and wisely adapted to, the state and condition of that sort of Animals, who are thus made: So that the Wisdom and Goodness of the Maker plainly appears in all the Parts of this stupendous Fabrick, and all the several degrees and ranks of Creatures in itâ (p. 148). He added: â œAnd therefore, I think we may suppose, That â ™tis in this, that the Species of *Brutes* are discriminate from Man; and â ™tis that proper difference wherein they are wholly separated, and which at last widens to so vast a distance. For if they have any *Ideas* at all, and are not bare Machines (as some would have them) we cannot deny them to have some Reason. It seems evident to me, that they do some of them in certain Instances reason, as that they have sense; but it is only in particular *Ideas,* just as they received them from their Senses. They are the best of them tied up within those narrow bounds, and *have not* (as I think) the faculty to enlarge them by any kind of *Abstraction*â (p. 160) Arthur Schopenhauer wrote in 1851: â œThe life of the *plants* consists in simple *existence:* so that their enjoyment of life is a purely and absolutely subjective, torpid contentment. With the *animals* there enters *knowledge:* but it is still entirely restricted to what serves their own motivation, and indeed their most immediate motivation. That is why they too find complete contentment in simple existence and why it suffices to fill their entire lives; so that they can pass many hours completely inactive without feeling discontented or impatient, although they are not thinking but merely looking. Only in the very cleverest animals such as dogs and apes does the need for activity, and with that boredom, make itself felt; which is why they enjoy playing, and why they amuse themselves by gazing at passers-by; in which respect they are in a class with those human window-gazers who stare at us everywhere but only when one notices they are students really arouse our indignationâ (1970, p. 126).

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P. 48: DARWIN

Darwin (1872) wrote: â œMany years ago, in the Zoological Gardens, I placed a looking-glass on the floor before two young orangs, who, as far as it was known, had never before seen one. At first they gazed at their own images with the most steady surprise, and often changed their point of view. They then approached close and protruded their lips towards the image, as if to kiss it, in exactly the same manner as they had previously done towards each other, when first placed, a few days before, in the same room. They next made all sorts of grimaces, and put themselves in various attitudes before the mirror; they pressed and rubbed the surface; they placed their hands at different distances behind it; looked behind it; and finally seemed almost frightened, stared a little, became cross, and refused to look any longer-â (p. 140). Darwin (1998, orig. 1871) wrote: â œSome naturalists, from being deeply impressed with the mental and spiritual powers of man, have divided the whole organic world into three kingdoms, the Human, the Animal, and the Vegetable, thus giving man a separate kingdom. Spiritual powers cannot be compared or classed by the naturalist: but he may endeavor to show, as I have done, that the mental faculties of man and the lower animals do not differ in kind, although immensely in degree. A difference in degree, however great, does not justify us placing man in a distinct kingdomâ ¦â (p. 152). The first quote in the main text is from Darwin (1968, orig. 1859, p. 234). The quote on ants is from Darwin (1871, pp. 152â “53).

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p. 50: Morganâ ™s Canon

See Morgan (1894, p. 53). According to Griffin (1976): â œOccamâ ™s razor and Morganâ ™s canon have been so seriously adhered to since the 1920s that behavioral scientists have grown highly uncomfortable at the very thought of mental states or subjective qualities in animals. When they intrude on our scientific discourse, many of us feel sheepish, and when we find ourselves using such words as fear, pain, pleasure, or the like we tend to shield our reductionist egos behind a respectability blanket of quotation marksâ (p. 47).

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p. 50: Huxley

The quote is from Huxley (1923, pp. 105-6).

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p. 51: Japanese Primatology

Asquith (1997) writes: â œSome of the effects of different conceptions of the human/animal relationship on Japanese and Western studies of primates have been noted. Japanese reports about animalsâ ™ motives, personalities and lives were, in their Western colleaguesâ ™ eyes, highly anthropomorphic. As rationality is so central to the Western debate about human uniqueness, it is not surprising that the strongest invectives against anthropomorphism are about attributing rationality to other animals. Emotionality for the Westerner comprises a subset of arguments about rationality and, as mentioned, there is not universal agreement about it, even among scientists. To the Japanese researchers, questions about the rational uniqueness of humans did not arise and their reports were filled with mentalistic language. Western response to such reportage as unscientific, and hence dismissable, resulted in more than two decadesâ ™ lag behind the Japanese in certain theoretical developments in primatologyâ

(p. 29). De Waal (2001) writes: â œWhen Japanese primatologists went to Africa to observe great apes in their natural habitat, they arrived with excellent training and their hallmark approach of persistent, long-term data gathering that was to become the standard. Like Goodall, they habituated the objects of their study to human presence through food provisioning. Major discoveries were made by these scientists, such as that chimpanzees live in well-delineated groups, and that they use lithic tools that, had they been associated with people, would have qualified them for the Stone Ageâ (p. 117). De Waal writes about Sugiyamaâ ™s discovery of infanticide among langur monkeys: â œThe discovery was ignored for about a decade, after which other reports of infanticide surfaced, first in other primates and eventually in many other animalsâ ”from lions and prairie dogs to dolphins and birds. I have never witnessed such turmoil at primatological conferences as in the days when infanticide became a growing topic. Reports provoked shouting matches, accusations of inadequate evidence (most of it was postmortem), and utter disbelief that the same theories that speak of reproductive success could be enlisted to account for the annihilation of newbornsâ (pp. 184â “85). See also Asquith (1986).

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p. 52: Skinner

Skinner (1959) wrote: â œPigeon, rat, monkey, which is which? It doesnâ ™t matter. Of course, these three species have behavioral repertoires which are as different as their anatomies. But once you have allowed for differences in the ways in which they make contact with the environment, and in the ways in which they act upon the environment, what remains of the behavior shows astonishingly similar propertiesâ (pp. 125â “26).

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p. 52: Thomas

The quote is from Thomas (1974, p. 12).

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p. 53: Occamâ ™s Razor Questioned

Oreskes et al. (1994) write: â œIf two theories (or model realizations) are empirically equivalent, then there is no way to choose between them other than to invoke extraevidential considerations like symmetry, and elegance, or personal, political, or metaphysical preferencesâ ¦Ockhamâ ™s razor is perhaps the most widely accepted example of an extraevidential consideration. Many scientists accept and apply the principle in their work, even though it is an entirely metaphysical assumption. There is scant empirical evidence that the world is actually simple or that simple accounts are more likely than complex ones to be true. Our commitment to simplicity is largely an inheritance of 17th-century theologyâ (pp. 642â “45). Hoffman et al. (1996) write in their essay â œOckhamâ ™s Razor and Chemistry:â â œTime and time again the process of discovery in science reveals that what was thought simple is really wondrously complicatedâ (p. 123). Computer scientist Geoffrey Webb found that nine times out of ten computers using complex decision-making processes give more accurate results, and declared: â œPeople are missing out on useful patterns because theyâ ™re just looking for the simple ones. Occamâ ™s razor influences and limits what science can do with informationâ (quoted in *Discover,* November 1996, p. 35). Theoretical cosmologist James Peebles (2003) writes: â œEach time we formulate a hypothesis, we take the simplest one possible. But what obliges the Universe to be simple?â (p. 70).

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P. 53: ANTHROPOMORPHISM REHABILITATED

Cenami Spada (1997) writes: â œIf animals are categorized as machines, only the terminology used to describe machines will sound adequateâ ¦. If animals are not machines, we need to study to what extent similarities and differences with human behaviors can be drawn. In doing this we unavoidably refer to our experience: what else could we refer to when studying animals!â (pp. 43â “44). The quote in the main text is from de Waal (2001, p. 40).

CHAPTER 5

P. 55: BEES HANDLE ABSTRACT CONCEPTS

See â œThe concept of â ˜samenessâ ™ and â ˜differenceâ ™ in an insectâ by Giurfa et al. (2001), who write: â œOur results question the view that vertebrates, and in particular primates, may be the only animals able to form â ˜samenessâ ™ or â ˜odditiyâ ™ concepts. They also show that higher cognitive functions are not a privilege of vertebratesâ (p. 932). Giurfa interviewed by Davidson (2001) declared: â œI disagree with your characterization of this being a â ˜low-degreeâ ™ of intelligence. In fact, it would be the opposite! (In the past) many researchers thought that this kind of learningâ ”learning an abstract rule, which is independent of the stimuli usedâ ”can only be possible in primates and human beings. Here (in this experiment) we show that this is not true. Abstract rules can also be mastered by the mini brain of a honeybeeâ (p. A-1).

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p. 57: Bees Are Not Automata

Menzel and Giurfa (2001) write: â œInsects have traditionally been considered simple and small reflex automata. However, this particular view overlooks the fact that insects, like most living organisms, flexibly process information in order to adapt to their environmentâ ¦insects are evolutionarily extremely successful, having penetrated all habitats and outnumbering by far all other multicellular organisms, both in absolute and in species numbers. The insect brain must therefore provide intelligent solutions to a wide range of ecologically relevant problems in order to assure such evolutionary successâ (p. 62).

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p. 59: Swarm Intelligence

Leslie (2002) writes under the heading â œWhat a bunch of dumb insects can teach us about intelligenceâ : â œThe insects exhibit what computer scientists call swarm intelligence: each individual is dim-witted, but the collective actions of the many produce apparently smart behavior, like a brain relying on millions of simple neurons. For instance, if you put an obstacle in the path of a column of foraging ants, they will find the shortest way around itâ (p. 45).

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p. 59: Emergence

Johnson (2001) writes in his book *Emergence: The Connected Lives of Ants, Brains, Cities, and Software:* â œThe simplicity of the ant languageâ ”and the relative stupidity of the individual antsâ ”is, as the computer programmers say, a feature not a bug. Emergent systems can grow unwieldy when their component parts become excessively complicated. Better to build a densely interconnected system with simple elements, and let the more sophisticated behavior trickle upâ ¦Having individual agents capable of directly assessing the overall state of the system can be a reliability in swarm logic, for the same reason that you donâ ™t want one of the neurons in your brain to suddenly become sentientâ (p. 78). He adds: â œAn important distinction must be drawn between ant colonies and cities, though, and it revolves around the question of volition. In a harvester ant colony, the individual ants are relatively stupid, following elemental laws without anything resembling free will. As we have seen, the intelligence of the colony actually relies on the stupidity of its component parts: an ant that suddenly started to make conscious decisions about, say, the number of ants on midden duty would be disastrous. You can make the case that this scenario doesnâ ™t apply at all to human settlements: cities are higher-level organisms, but their component partsâ ”humansâ ”are far more intelligent, and more self-reflective, than ants are. We consciously make decisions about where to live or shop or stroll; weâ ™re not simply driven by genes and pheromones. And so the social patterns we form tend to be substantially more complex than those of the ant worldâ (p. 97).

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p. 62: Insect Pain

Wigglesworth (1980) writes: â œPerhaps the most significant result of the â ˜Molecular Biologyâ ™ of the past 25 years is the bond it has established between ourselves and the â ˜lower animals.â ™ They have become so close to us. Indeed, nowadays one has the same feeling of unease in speaking of the â ˜lower animalsâ ™ as one would in referring to the â ˜lower classes.â ™ I think we should approach the problem of pain by thinking of the insect as a little human beingâ ¦For the most part insects behave as though their integument is insensitive to pain. They show no manifestation of pain on cutting the cuticule: they cannot cry out, but they do not flinch or run. Whereas a nip with forceps is very painful to us, a caterpillar treated in this way shows no sustained signs of agitationâ ¦I believe that most of the manipulations to which we commonly subject insects are not causing them painâ ¦But I am sure that insects can feel pain if the right stimulus is given. High temperature seems the clearest example, and perhaps electric shocks. For practical purposes why not assume that that is so? Most operations on insects are actually facilitated if the insect is narcotizedâ (pp. 8â “9). Bekoff (2002) writes: â œWhile researchers are not sure which animals feel pain there is much evidence that animals who many people thought could not feel pain in fact, do. Fish, for example, have neurons similar to those that are associated with the perception of pain in other animals. Fish show responses to painful stimuli that resemble those of other animals, including humans. Even some invertebrates possess nerve cells that are associated with the feeling of pain in vertebrates. Whether some insects actually feel pain is not known, but because they might some people believe that they should be given the benefit of the doubtâ (pp. 143â “44).

chapter 6

p. 69: Plants

Attenborough (1995) describes a Venus flytrap in action: â œAn insect, attracted by the nectar or the red coloration can crawl around on the surface of a lobe with impunity, provided it doesnâ ™t touch one of these bristles, for they are triggers. Even touching one is not necessarily lethal, for nothing will happen immediately. But if it touches the same one or another on the leaf within twenty seconds, thenâ ”with a swiftness that may alarm a watching botanist, accustomed as he is to more sedate reactions from his subjectsâ ”the two lobes snap together. The reaction takes no more than a third of a second. The stimulus that triggers it is an electric one, like that of the sensitive mimosa, but exactly what mechanism drives the closure is, even now, not fully understoodâ (pp. 84â “85).

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p. 70: Definition of â œAnimalâ

The *Concise Oxford Dictionary* defines an animal as â œa living organism which is typically distinguished from a plant by feeding on organic matter, having specialized sense organs and nervous system, and being able to move about and respond to stimuli.â

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p. 71: Sponges

Leys and Mackie (1997) write: â œSponges arose very early in metazoan evolution. They do not have a nervous system, but some respond to stimulation by producing local contractions and one group, the â ˜glass sponges,â ™ shows coordinated arrests of movements of the flagella, which produce the feeding current. We show here that these arrests are coordinated by propagated electrical impulses. This is, to our knowledge, the first report of electrical signaling in any spongeâ (p. 29). See also Leys et al. (1999).

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p. 71: Hydralike Creatures at the Origin of Head Development

Bhattacharjee (2003) writes: â œIn their quest for the origin of the head, scientists have identified genes in corals, sea anemones and hydra that are similar to genes responsible for head development in higher animals like flies and mice. Studying such homologous genes across species, which have closely matching protein sequences, is a standard technique used by researchers to trace the ancestry of physical and behavioral traits. In experiments on hydra, Dr. Brigitte Galliot and her colleagues at the University of Geneva studied genes that were similar to head-development genes in the fruit fly. They chopped off the top of a hydra and monitored the expression of specific proteins regulated by these genes as the organism regenerated its lost part. From the pattern of proteins expressed during the regeneration process, the researchers concluded that the genes were involved in forming the hydraâ ™s upper region, including the organization of nerve cellsâ ¦These findings suggest that the head in higher animals may have evolved from a mouth-like structure similar to the cnidarianâ ™s upper body, consisting of a nerve net around an oral opening. A larger conclusion, according to Dr. Galliot, is that the headâ ™s origin may have been driven by the need for active feedingâ (p. 2).

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P. 72: SNAILS

MusÃ©um National dâ ™Histoire Naturelle (1999): â œA snail possesses several thousand neurons. But impulses circulate at a very slow rhythm in its nervous system. Several seconds may elapse between the exterior stimulus and the muscular response. As far as seeing is concerned, the two thousand or so captors on each of its two eyes allow it to detect shadows which move slowlyâ ¦The snailâ ™s world is devoid of forms, colors and fast movementsâ (pp. 14â “15).

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P. 73: OCTOPUSES

Linden (2002) writes: â œThe one characteristic the octopus shares with a number of intelligent animals is the need to seek a wide variety of foods in varied and concealed placesâ (p. 47) He adds: â œIf we think about octopus snubs, octopus anger, and octopus raids on neighboring tanks, we have to start thinking afresh about the relationship of brain size to intelligence and about different types of intelligence, as well as the forces that make one animal more intelligent than another. Thatâ ™s not a bad thing. The riddle of the octopus may or may not lead to a new approach to animal intelligence, but it is certainly worth ponderingâ (p. 54).

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P. 74: FUNDAMENTAL COMMONALITIES BETWEEN NEMATODES AND HUMANS

Wade (1997) writes about nematode *C. elegans:* â œAnother surprise has been the closeness of its genetic kinship to humans. Most of the human genes being discovered turn out to have counterpart genes in the worm, ones so similar in chemical structure that they must have evolved from the same parent DNA in the distant common ancestor of both worms and humans. Even after all these eons, the closeness is real enough that in several cases biologists have been able to insert the human version of a gene in place of the wormâ ™s own copy. *C. elegans* gets along just fine with its human replacement partâ (p. B9).

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P. 76: Human Origins

Wilford (2003) writes: â œThe discovery of the oldest near-modern human remains, announced Wednesday, is considered a major step in establishing the time and place for the emergence of anatomically modern *Homo sapiens*â ”probably about 150,000 years ago, as genetic studies have suggested, in Africaâ (p. 1). Stringer (2003) writes: â œThere are two broad theories about the origins of *H. sapiens.* A few researchers still support a version of the â ˜multiregionalâ ™ hypothesis, arguing that the anatomical features of modern humans arose in geographically widespread hominid populations throughout the Pleistocene epoch (which lasted from around 1.8 million to some 12,000 years ago). But most now espouse a version of the â ˜out of Africaâ ™ model, although there are differences of opinion over the complexity of the processes of origin and dispersal, and over the amount of mixing that might subsequently have occurred with archaic (nonmodern) humans outside Africa. Within Africa, uncertainties still surround the mode of modern human evolutionâ ”whether it proceeded in a gradual and steady manner or in fits and startsâ (p. 692). Kuper (1994) writes: â œ*Australopithecus* had brain volumes ranging from 375ml. to about 485ml. In *Homo habilis,* the mean volume was about 750ml. From *Homo erectus* on there was a gradual growth of brain volume from some 800 ml. to the average of modern *Homo sapiens,* which is about 1,400 ml.â (p. 24).

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P. 77: Neanderthals and Homo Sapiens Sapiens

Fagan (1990) writes: â œThe Neanderthals had broad shoulders and very powerfully developed upper arm musculature, much more powerful than that of *Homo sapiens sapiens.* Their fingers were identical in form to modern ones, but Neanderthal thumbs were capable of exerting exceptional force during normal grips. In contrast, early anatomically modern humans had much less powerful grips. The same difference in robusticity is found in the lower limbs. Compared with modern humans, Neanderthals had much more sturdy leg bones and powerful knees, which enabled them to generate considerable force around the kneeâ ¦This robustness was an important part of the Neanderthalsâ ™s biological adaptation. It enabled them to generate and sustain more strength and habitually higher levels of activity than most modern humans. However, maintaining such a body was costly in terms of energy, an important consideration for hunter-gatherer populations that, like most groups of people, were close to the limits of their energy resourcesâ   (p. 80). Hoffecker (2002) writes: â œThere is significant negative evidence that hides were not used by the Neanderthals to produce tailored clothing comparable to that of modern hunter-gatherers of arctic regionsâ ¦Even more important is the complete absence of bone needles in Mousterian sites, despite preservation and recovery of small bone fragments from many localities. By contrast, eyed bone needles appear in the earliest modern human sites in Eastern Europe and Siberiaâ   (p. 107). He adds: â œThe predominance of meat in the diet is indicated by stable isotope analyses of bone collagen from Neanderthal skeletal remains in Western and Central Europe. Heavy reliance on meat may also be inferred from evidence for the hunting of large mammals from Neanderthal sites in Europe and the Near Eastâ   (p. 133). And: â œBoth in terms of the number of types and component parts of individual implements, the complexity of Neanderthal tools and weapons is significantly lower than that of hunter-gatherers in northern latitudes (and more typical of modern groups in temperate or equatorial regions)â ¦Equally important is the apparent lack of technologyâ ”found among modern humansâ ”for cold protection and heat conservation. Although microwear analyses of stone tools indicate that the Neanderthals often scraped hides (especially in Eastern European sites), which were presumably used as blankets and simple clothing, there is no compelling evidence for tailored fur clothing or insulated shelters. Perhaps the critical function of the latter is that they provide protection from extreme low temperatures in a form that permits humans to forage and perform other important economic tasks (e.g., tool manufacture)â   (p. 135). Stringer (2003) writes, referring to recently discovered fossils in Ethiopia: â œThe new finds from Herto represent early *Homo sapiens*. This reflects the view that both Neanderthals and modern humans derived from a widespread ancestral species called *H. heidelbergensis*. However, evidence is growing that Neanderthal features have deep roots in Europe, so *H. Neanderthalensis* might extend back over 400,000 years. The roots of *H. sapiens* might be similarly deep in Africaâ   (p. 693).

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P. 78: Species Disappeared with the Arrival of Homo Sapiens Sapiens

Ridley (1996) writes: â œThe guilt of the human species is not in doubt. Take Madagascar, where at least seventeen species of lemurs (all the diurnal ones larger than ten kilograms in weight, one as big as a gorilla), and the remarkable elephant birdsâ ”the biggest of which weighed 1,000 poundsâ ”were dead within a few centuries of the islandâ ™s first colonization by people in about 500 A.D. It was a process repeated throughout the Pacific by the Polynesians and most spectacularly of all just six hundred years ago on New Zealand, where the first Maoris sat down and ate their way through all twelve species of the giant moa birds (the biggest weighing a quarter of a ton)â ¦On Hawaii, we now know that there were about

100 species of unique Hawaiian birds, many of them large and flightless. Then, about 300 A.D., a large mammal called humankind arrived. Within a short time no fewer than half of the Hawaiian birds were extinctâ ¦: It took a little longer to wipe out Australiaâ ™s large mammals. Yet soon after the arrival of the first people in Australia, possibly 60,000 years ago, a whole guild of large beasts vanishedâ ”marsupial rhinos, giant diprotodons, tree fellers, marsupial lions, five kinds of giant wombat, seven kinds of short-faced kangaroos, eight kinds of giant kangaroo, a two-hundred-kilogram flightless bird. Even the kangaroo species that survived shrank dramatically in size, a classic evolutionary response to heavy predationâ (pp. 218â “19).

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p. 79: â œNatureâ

The *Concise Oxford Dictionary* defines nature as â œthe phenomena of the physical world collectively, including plants, animals, and the landscape, as opposed to humans or human creations.â Disengaging from â œnatureâ allows one to have a concept of it. Ingold (1997) writes: â œWhat I can do, that the animal supposedly cannot, is to take a step back from the physical dimension of existence, and to witness life in this dimension as a spectacle. It is to this spectacle, as presented to a subject disengaged from it, that we commonly refer by the concept of â ˜nature.â ™ Indeed, a world can only be â ˜natureâ ™ for a being that does not belong there. If the concept of nature thus implies a disengagement from the world, then the possibility of disengagement, in turn, is taken to be the hallmark of the condition of humanity. Human uniqueness is supposed to lie precisely in this: that whereas the differences among animal species are differences *in* nature, humans are different in being half in nature, half out. We are *in* nature to the extent that we are organisms with bodies, which depend on a throughput of materials and energy for their maintenance and reproduction. We are *out of* nature to the extent that we are persons with minds, with which we are able to reflect upon and represent the circumstances of our bodily experience. This reflexive process, according to conventional anthropological wisdom, is one of investing experience with meaning, and the source of all meaning is cultureâ (p. 113).

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p. 80: Size of Human Cortex

Passingham (2002) writes: â œIt was argued long ago that what may be critical for intelligence is the absolute amount of tissue (or number of neurons) above that accounted for by the general relation between brain size and body size. Larger bodies require larger brains, but for any particular body size the different mammalian groups differ in brain size, with the primates having especially enlarged brains. The human neo-cortex is over three times as large as expected for a primate matched for body size. Even though the present study shows that the human frontal lobes do not differ as a proportion of the neo-cortex, they are over three times larger than would be expected for a hypothetical great ape of the same body weight. Such a difference must be of immense consequence for our capacity to plan and reasonâ (pp. 191â “92). The quotes in the main text are from Carter (1998, p. 35) and Greenfield (2000, p. 164).

CHAPTER 7

P. 83: PLANTS CRY FOR HELP

Whitfield (2001) writes: â œPlants cannot run from trouble, but neither do they lie down and surrender. As well as producing a variety of noxious chemicals to deter herbivores, they can enlist help from higher up the food chain, releasing volatile chemicals that attract predators to eat the creatures that are eating themâ ¦Researchers estimated that, by releasing volatiles, tobacco plants could reduce the number of herbivores attacking them by more than 90 percent-â (pp. 736-37). Buhner (2002) writes: â œIn response to overfeeding by aphids some plants will release a volatile aromatic, E-beta-fanesene, from their leaves. This mimics an aphid alarm pheromone warning of approaching predators, telling them to flee the plant. Spider miteâ “infested lima beans will release a blend of volatile oils (terpenoids) that attracts a predatory mite that feeds on spider mites. The plants can tell exactly what kind of mite is feeding on them through analyzing the chemistries of their saliva. Each plant species then produces a different blend of volatiles depending on what kind of spider mite is feeding on it. That mix will *only* call the predator that feeds on that kind of mite. The plants also tell other, uninfested, lima beans what is happening. Those receiving the communication also begin to release the chemical that calls predatory mites, thus reducing the spread of the feeding mitesâ (p. 162). Marcel Dicke, who first carried out the research on mites and lima beans is quoted by Russell (2002): â œToday, the scientific community agrees that plants talking to their bodyguards is likely to be a characteristic of most, if not all, plant speciesâ ¦If plants talk to their bodyguards, then why would their neighbors not take advantage of that and eavesdrop on the message? The topic of plant-to-plant communication is back on the agenda, and the evidence is accumulatingâ (p. 49). Ryan (2001) writes: â œVolatile chemicals are the language of plants. Through the smell of fresh blossoms, good coffee or a fine wine, their message to humans can be attractive. But plants do not expend valuable energy making these chemicals simply to please humans, and most volatiles have more serious functions. Some, for instance, are important in communicating information to particular insects that is crucial to the survival of the plants, and often the insects as wellâ ¦At night, tobacco plants that are being attacked by caterpillars emit a specific blend of volatile chemicals. Nocturnal moths interpret these chemicals as a signal that they will not be welcome to lay their eggs there. But it isnâ ™t just the plant that benefits from these night-time emissions. As the plant is making nasty chemicals to ward off the caterpillars, and may be summoning help from predatory insects, it is advantageous for the moths to keep awayâ (p. 530). See Trewavas (2002) for the article quoted in the first paragraph of the main text.

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p. 85: Stenhouseâ ™s Definition of Intelligence

See Stenhouse (1974, p. 31).

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p. 86: Stilt Palms and Ground Ivy

Trewavas (2003) writes: â œThe stilt palm is constructed from a stem raised on prop roots. When competitive neighbors approach, avoidance action is taken by moving the whole plant back into full sunlight. Such obvious â ˜walkingâ ™ is accomplished by growing new prop roots in the direction of the movement while those behind die off. That this is intentional behavior is very clearâ (p. 15). Phillips (2002) writes: â œRoots can follow mineral or moisture gradients in the soil, but they donâ ™t always take the simple route. Hutchings and his colleagues have studied the foraging behavior of a creeping herb called *Glechoma* (ground ivy). When theyâ ™re in good soil these herbs grow more branches, shoots and leaves. They also form clumps of root much faster to fully exploit the patch. But when theyâ ™re on poorer territory they spread farther and faster, almost as if theyâ ™re escaping, and their rhizomes are generally thinner and branch less frequently. This means that new shoots develop further from the parent plant and actively search for new resource-rich patches. And the amount of growth is not related just to the absolute quality of a patch, but to how good it is relative to surrounding soils. Not only that, but experiments have shown that related plants can sense the presence of competitorsâ ™ roots and head off to other areasâ ”even when thereâ ™s still lots of food aroundâ (p. 41). And Wijesinghe and Hutchings (1999) write: â œIn conclusion, this study revealed a close match between resource availability and the placement of resource-acquiring structures under all but the most heterogeneous conditions, and greater morphological specialization when resources were distributed in large patches with high contrast in quality. *Glechoma hederacea* clearly has an acute perception of the quality of its environment, and responds to it through foraging and local morphological specializationsâ (p. 871).

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P. 87: Plants Face a Wide Variety of Environments

Trewavas (1999a) writes: â œWhat particular problems faced by plants require intelligent behavior? Wild seedlings must grow where they land. The external environment is composed of probably 17 distinct constituents and, being variable in intensity even from minute to minute, generates an almost infinite variety of environmental states. There are probably as many internal plant signals that either pass through or are perceived at the plasma membrane. In responding intelligently to this multiplicity of signals, plants have become masters of phenotypic and physiological plasticity, which allows them to cope with the variable circumstances that surround them. Behavioral plasticity surely demands a cellular system of considerable computing power if plants are to survive the signal morass in which they find themselves. The ubiquity of calcium involvement in plant-cell signal transduction suggests that calcium forms the basis of the intelligent system controlling plasticityâ (p. 5).

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P. 88: Dodder Makes Intelligent Decisions

According to Kelly (1992), who did the original research demonstrating active choice by dodder: â œWhether the potentially adaptive ability to choose resources is accessible to all plants or is dictated by the cloning ability or para sitism of dodder is unknown. However, the increased efficiency of resource acquisition that modular â ˜choiceâ ™ could provide would be beneficial to any plant, parasitic, clonal, or otherwiseâ ¦The results presented here also necessarily show active choice on the part of a parasitic plant and outline a means by which choice might be tested for other parasitic angiospermsâ (p. 12196). Gilroy and Trewavas (2001) write: â œDecisions about exploitation of basic nutrient resources can be made by plants before any nutritional benefit is derived. Dodder, a parasitic plant, can sense the level of circulating nutrients when it first touches a putative host. Within one hour, it â ˜decidesâ ™ whether it is worth initiating a developmental program, which involves shoot-coiling around the host and the formation of haustoria several days later. Rejection of the putative host is frequent. Once haustoria penetrate the host vascular system, nutrients are gained and used for growth. Remarkably, the number of coils of the parasite around the host stem reflects with some accuracy the nutrients in the host and the likely subsequent return in growth resources. What is required of plant-cell signal-transduction studies, then, is to account for the capacity for â ˜intelligentâ ™ decision-making; computation of the right choice between close alternativesâ (p. 308).

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P. 89: Calcium and Learning in Plants and Neurons

Trewavas (1999b) writes: â œIn an unstimulated plant, information flow from a signal through Ca^{2+} (calcium ion)-dependent pathways will be slow; in a stimulated plant, information flow from the self-same signal will be enormously faster. However these data are viewed, they represent a form of cellular learningâ ¦Signal-transduction networks share properties with neural networks, and the learning parallels can be drawn easily. Neural networks learn by increasing the numbers of connections (and the strength of the connections) between the neurons representing the chosen path to connect signal and response. The result of learning (reinforcement) is to accelerate the information flux rates between the signal and the response. Elevating calcium ion transduction constituents is analogous to increasing the numbers of connections in a neural network. The increased information flow that results represents a kind of cellular learning. This cellular learning, coupled with the memory built into signal-transduction systems, suggests an unexpected form of cellular intelligenceâ (p. 4218). See Gilroy, Read and Trewavas (1990) for the initial research on calciumâ ™s role in plant cells. Toni et al. (1999) write: â œStructural remodeling of synapses and formation of new synaptic contacts has been postulated as a possible mechanism underlying the late phase of long-term potentiation (LTP), a form of plasticity which is involved in learning and memory. Here we use electron microscopy to analyze the morphology of synapses activated by high-frequency stimulation and identified by accumulated calcium in dendritic spines. LTP induction resulted in a sequence of morphological changes consisting of a transient remodeling of the postsynaptic membrane followed by a marked increase in the proportion of axon terminals contacting two or more dendritic spines. Three-dimensional reconstruction revealed that these spines arose from the same dendrite. As pharmacological blockade of LTP prevented these morphological changes, we conclude that LTP is associated with the formation of new, mature and probably functional synapses contacting the same presynaptic terminal and thereby duplicating activated synapsesâ (p. 421). Ottersen and Helm (1999) comment that neuronal spines â œare tiny protrusions from long, slender extensions (dendrites) of nerve cells, and they constitute the receiving parts of synapsesâ ”the contacts that mediate neuron-to-neuron signaling. Spines are believed to be the most basic functional units in the brain, and their large number (of the order of 10^4 per neuron) helps to explain the impressive memory-storage capacity of the cerebral cortexâ (p. 751).

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P. 90: Trewavasâ ™s Method for Finding Ideas

Beveridge (1950) writes in his book *The Art of Scientific Investigation:* â œThe most important prerequisite is prolonged contemplation of the problem and the data until the mind is saturated with it. There must be a great interest in it and desire for its solution. The mind must work consciously on the problem for days in order to get the subconscious mind working on itâ ¦An important condition is freedom from other problems or interests competing for attention, especially worry over private affairsâ ¦Another favorable condition is freedom from interruption or even fear of interruption or any diverting influence such as interesting conversation within earshot or sudden and excessively loud noisesâ ¦Most people find intuitions are more likely to come during a period of apparent idleness and temporary abandonment of the problem following periods of intensive work. Light occupations requiring no mental effort, such as walking in the country, bathing, shaving, traveling to and from work, are said by some to be when intuitions most often appearâ ¦Others find lying in bed most favorable and some people deliberately go over the problem before going to sleep and others before rising in the morningâ (p. 76).

CHAPTER 8

P. 95: SLIME MOLDS

Stephenson and Stempen (1994) write: â œSlime molds, or myxomycetes, as biologists call them, may not have a particularly attractive name, but members of the group produce fruiting bodies that exhibit incredibly diverse forms and colors and are often objects of considerable beautyâ ¦Myxomycetes have long intrigued and perplexed biologists because they possess characteristics of both animals and fungi. The fruiting body and spores they produce resemble those of many fungi, but some of their other attributes, including the capability for locomotion, are normally associated with animals. For most of its life, a myxomycete exists as a thin, free-living mass of protoplasm. Sometimes this mass is several centimeters across and, as the name slime mold suggests, viscous and slimy to touch. The mass of protoplasm, which is called plasmodium (plural: plasmodia), can change form and creep slowly over the substrate upon which it occurs, much like a giant amoeba. As it moves, it feeds by engulfing bacteria and tiny bits of organic matter, another animal-like featureâ (pp. 13â “14). Zimmer (1998) describes multi-cellular slime mold *Dictyostelium* in action: â œRather than crawling around randomly, the amoebas start streaming toward one another in inwardly pulsing ripples. As many as 100,000 converge in a swirling mound. And then, remarkably, the mound itself begins to act as if it were the organism. It stretches out into a bullet-shaped slug the size of a sand grain and begins to move. It slithers up toward the surface of the soil, probes specks of dirt, and turns around when it hits a dead end. Its movements are slowâ ”it would need a day to travel an inchâ ”but in a stop-action filmâ ¦the deliberateness of the movements eerily evoke an *it* rather than a *they.* After several hours, the *Dictyostelium* slug goes through another change. The back end catches up with the tip. The blob stretches upward a second time, and now some amoebas produce rigid bundles of cellulose. They die in the process, but their sacrifice allows the blob to become a slender stalk. Perched atop the stalk is a globe, bulging with living amoebas, each of which covers itself in a cellulose coat and becomes a dormant spore. In this form the colony will wait until somethingâ ”a drop of rainwater, a passing worm, the foot of a birdâ ”picks up the spores and takes them to a bacteria-rich place where they can emerge from their shells and start their lives overâ (p. 88).

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P. 96: SLIME MOLD SOLVES MAZE

Nakagaki (2001b) writes: â œIt is a common insult in Japan to hear someone ridiculed as â ˜one-cellular,â ™ indicating minimal mental capacity on the part of the subject of the remark. But this put-down may lose some of its bite in the future, because our research has demonstrated that the true slime mold, a giant unicellular organism with multiple nuclei, is able to solve a maze and other combinatorial optimization problemsâ ¦While it lacks a nervous system, legs or eyes, the plasmodium is still able to move its mass to wherever it finds food. The mere oddities of this strange-looking animal have provided sufficient material for several research papers, even without my having gained any special insights into its behavior, so we have continued to observe it closely. It was about four years ago, as I merely cultivated and observed the plasmodium, that the unexpected and surprising cleverness that it displayed gave me the idea of publishing what we had learnedâ (p. 8). The first quote in the main text is from â œMaze-Solving by an Amoeboid Organism,â by Nakagaki et al. (2000, p. 470). Nakagakiâ ™s second quote is from â œIs Slime Intelligent?â by Viegas (2000, p. 1).

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P. 103: SLIME MOLDâ ™S EFFICIENT TUBING NETWORK

Nakagaki et al. (2004) write: â œHow does the organism obtain the smart solution? Two empirical rules describing changes in body shape are known: 1) tubes of open ends are likely to disappear in the first step and 2) when two or more tubes connect the same two food sources, the longer tubes tend to disappear. These changes in the tubular structure of the plasmodium are closely related to the spatio-temporal dynamics of cellular rhythms. Shuttle streaming of protoplasm, which is driven by hydrostatic pressure induced by rhythmic contraction, may affect the morphogenesis of tubular structures. Hence a key mechanism underlying network formation may involve the spatio-temporal dynamics of oscillatory fields with complex shapes and moving boundaries. The *Physarum* plasmodium can construct an efficient transportation network which meets the multiple requirements of short length of network and low degree of separation between food sources, as well as tolerance of accidental disconnection at random position. The plasmodium can achieve a better network configuration than that based on the shortest connection of Steinerâ ™s minimum tree, which is impressive considering that it is very hard for humans to deduce Steinerâ ™s connections for just a few locations. This amoeboid organism must be quite smartâ (pp. 4â “5). Nakagaki et al. (2001) write: â œBiochemical oscillators in the plasmodium may give rise to propagating waves by spatial interactions of diffusion and advection via protoplasmic streaming. These intracellular waves can be initiated by some external stimulation including the addition of nutrients, the increase of light intensity, humidity, or temperature. The traveling wave leads to the development of a tubular structure in the sheet-like parts. Therefore, the geometry of the tube network drastically changes, depending on the external perturbation.. The path-finding mechanism is closely related to the contraction waves in the plasmodium. The addition of the nutrient leads to a local increase in the contraction frequency which initiates wave propagation from the site of higher frequency. This induction of waves is explained by the theory of phase dynamics. Such contraction waves make the tube modified, since the tube is reinforced or decayed when it is parallel or perpendicular to the direction of propagation of the contraction waves. Therefore, effects of complex behavior of contraction waves in a maze on tube formation play a key role for path-finding in the true slime moldâ (pp. 47â “48, 50â “51).

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p. 105: Computation by Slime Mold

Nakagaki (2001a) writes: â œEven for humans it is not easy to solve a maze. But the plasmodium of true slime mold, an amoeba-like unicellular organism, has shown an amazing ability to do so. This implies that an algorithm and a high computing capacity are included in the unicellular organismâ ¦From the viewpoint of computational science, the plasmodiumâ ™s method of computing is interesting because there is no central processing unit like a brain, but rather a collection of similar parts of protoplasm. Computing is performed in these parts which are parallel and coupled with each other. This type of computing is called parallel computing. The mechanism or algorithm of parallel computing is a challenging target which should be clarified in terms of computer science and the physics of self-organized phenomena. *Physarum* is a helpful object for trying to do soâ (p. 767,769).

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p. 105: â œIntelligenceâ and Information Processing in Humans and Unicells

Nakagaki (2001b) writes: â œHumans have consciousness, i.e., we are aware of ourselves. This is generally what we call â ˜mind,â ™ that part of each of us which is aware that, for instance, â ˜I am looking at something green,â ™ or that remembers â ˜I rode a bicycle yesterday.â ™ The mind is reflexive: it is able to view itself objectively. It can view itself apart from the rest of the world as an abstract model, maybe even allowing it to come to a better self-understanding. One would likely be hard put to explain how one felt when looking at something green; and even if the person were aware of the origination of that particular feeling, it would not be possible to have another person step together with them into that individual realm of feeling to gain the same impression. Thus the world in which each of us resides may not necessarily coincide with those of others; rather our own, individual worlds are realms created in our own minds, identical with our individual identity, or self-consciousness. Thus, the world we exist in is not something outside of us; rather, each of us exists entirely alone in our own, separate worlds. Next letâ ™s consider the unconscious realm, a world which has a great deal of influence on consciousness. We have only to consider our own internal information-processing mechanisms to understand that most of them take place on the unconscious levelâ ¦I believe that such unconscious information-processing mechanisms exist, to a greater or lesser extent, in all living things (for instance, the grouping tendencies of ants, or paramecium). Is this kind of information processing to be considered intelligence? On the other hand, are people with no conscious awareness of themselves, such as one in a coma, or merely asleep, to be considered unintelligent? If we can answer these questions, then we should be able to answer the question as to whether or not single-celled animals possess intelligence. It is my goal to research and clarify these unconscious information-processing mechanisms, if possible at the material level. In this effort, I consider the slime mold to be a most important, perhaps even ideal, subjectâ (pp. 11â “12).

CHAPTER 9

P. 111: PHOTORECEPTORS ON BUTTERFLY GENITALIA

Arikawa (2001) writes: â œButterflies sense light with their genitalia. Four photoreceptor cells in the genitalia mediate this photosensitivity. Such photoreceptors, which exist in body parts other than eyes, are collectively called extraocular photoreceptorsâ ¦One of the most extensively studied cases is the photoreceptor cells in the pineal gland of the vertebrate brain. The pineal photoreceptors receive light to entrain animalsâ ™ daily activity. In arthropods, extraocular photoreceptors are roughly divided into two types, according to their general location. The first type is found in the central nervous system. A classic example is the crayfish caudal photoreceptor, a photoreceptive interneuron in the abdominal nervous system, which mediates an escape response upon light stimulation of the abdomen. The second type is found outside the central nervous system as sensory neurons, with the photoreceptive site located on the periphery of the animals. The existence of the peripheral type of photoreceptor had long been indicated in certain scorpions, but the first conclusively documented case was that of the butterfly genital photoreceptorâ (p. 219). As butterflies mate tail to tail, and cannot see their own genitalia with their eyes, Arikawa suggests that males somehow use the light signal detected by their genital photoreceptors for copulation. Whereas females use their genital photoreceptors to lay their eggs correctly. See Arikawa et al. (1980) for the original research on the photoreceptors on butterfly genitalia.

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p. 111: Butterflies See in Color

Kinoshita et al. (1999) write: â œThe butterflies were trained to feed on sucrose solution placed on a disk of a particular color in a cage set in the laboratory. After a few such training runs, a butterfly was presented with the training color randomly positioned within an array of disks of other colors, but with no sucrose solution. The results indicate that the butterflies learn rapidly to select the training color reliably among different colors. The training color was also correctly selected when it was covered with neutral density filters to reduce its brightness, or even when the color was presented together with disks of a variety of shades of gray. These results demonstrate convincingly, for the first time, that a butterfly has true color visionâ (p. 95).

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p. 111: Butterflies Have Color Constancy

Kinoshita and Arikawa (2000) write: â œColor vision is the ability to discriminate visual stimuli on the basis of their chromatic content regardless of their brightness. The reliability of color vision is reinforced by the phenomenon of color constancy, which enables animals to recognize an objectâ ™s color irrespective of the spectral content of the illuminating light. For example, to a human observer, a red apple appears red both in sunshine and in fluorescent light, although the irradiation spectra are distinctly different. This phenomenon is the color constancy of human visionâ (p. 3521). They add: â œWe trained newly emerged *Papilio xuthus* to feed on sucrose solution on a paper patch of a certain color under white illumination. The butterflies were then tested under both white and colored illumination. Under white illumination, yellow-and red-trained butterflies selected the correctly colored patch from a four-color pattern and from a color Mondrian collage. Under four different colors of illumination, we obtained results that were fundamentally similar to those under white illumination. Moreover, we performed critical tests using sets of two similar colors, which were also correctly discriminated by trained butterflies under colored illumination. Taken together, we conclude that the butterfly *Papilio xuthus* exhibits some degree of color constancy when searching for foodâ (p. 3521).

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P. 112: Richly Endowed Visual System of Butterflies

The quote in the main text is from Arikawa et al. (2004) which examines color vision and retinal organization in butterflies.

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P. 112: Butterflies See in Ultraviolet, Humans Do Not

Arikawa (1999) writes: â œThe human color vision system is so-called trichromatic, which is based on three types of cone photoreceptors, peaking in the blue, green, and red wavelength regionâ ¦A striking difference exists in the color vision systems of arthropods and humans, namely in the sensitivity to UV light. The absence of UV sensitivity in the human eye makes it difficult to imagine the visual world of arthropods, for the human observer is virtually blind to the many patterns in natural scenes produced by UV reflection and absorptionâ (p. 23).

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P. 113: Human Vision and Color-Blindness

Ensminger (2001) writes: â œThe colors we see depend on the wavelength sensitivities of the visual receptors within our eyes as well as the wavelengths of light that enter our eyes. In color vision light excites different classes of photoreceptor cells, containing different visual pigments, and the brain compares their differential light absorption. Thus in bright light humans see a colorful world because the cone cells in our retinas have three visual pigments, with maximal sensitivities in the blue (Â±425nm), green (Â±530nm), and red (Â±560nm) regions of the spectrum, and the differential responses of these cells enables color visionâ ¦The importance of our visual pigments in determining the perception of color is perhaps best illustrated by â ˜color-blindness.â ™ This genetic disorder, which occurs in about one of twelve males and one of one hundred females, is caused by a defective visual pigment gene or the loss of a gene that codes for the red or green visual pigment. Although people with this disorder perceive the world very differently, they are not truly color-blind, for they still have two bright-light visual pigments and use these for dichromatic color vision, a more rudimentary type of color vision. True color-blindness occurs in people who lack both the red and green visual pigments; this condition is extremely rare, occurring in fewer than one person in thirty thousandâ (pp. 31â “32).

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P. 115: MODESTY IS A JAPANESE VIRTUE

Davies and Ikeno (2002) write: â œThere is a saying in Japanese that is related to the use of modesty: â œ*No aru taka wa tsume wo kakusu,*â or â œA clever hawk conceals its talonsâ ; i.e., genuinely capable people do not make a show of their abilities. In other words, in Japanese society, it is not good to parade oneâ ™s knowledge, culture, and ability; in fact, it can be dangerous, because students who show their abilities too openly in school or people who excel in society are often bullied or ostracized by othersâ (p. 149).

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P. 117: MINIATURIZATION IN JAPANESE DESIGN

See Davey (2003, p. 95).

CHAPTER 10

P. 123: HUMAN, MAMMALIAN, AND VERTEBRATE BRAINS

Blakeslee (2003) writes: â œThe search for brain differences has not been easy. Mammalian brains are extraordinarily similar. All contain an outer ring, or cortex. The human cortex, where intelligence lies, is simply a lot bigger than that of other creatures given the human bodyâ ™s sizeâ (p. 7). LeDoux (2002) writes: â œEvery vertebrate brain can be divided into three broad zones: the hindbrain, midbrain, and forebrainâ (p. 34).

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P. 124: DESCARTESâ ™*Treatise of Man*

See Descartes (1972, orig. 1662, p. 113). I have translated from the French original (Descartes 1953, p. 873) for the quote in the main text.

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p. 125: Living Beings Are Unlike Machines

Denton (2002) writes: â œEvery living system replicates itself, yet no machine possesses this capacity even to the slightest degree. Nor has any machineâ ”even the most advanced envisaged by nanotechnologistsâ ”been conceived of that could carry out such a stupendous act. Yet every second countless trillions of living systems from bacterial cells to elephants replicate themselves on the surface of our planet. And since lifeâ ™s origin, endless life forms have effortlessly copied themselves on unimaginable numbers of occasions. Living things possess the ability to change themselves from one form into another. For example, during development the descendants of the egg cell transform themselves from undifferentiated unspecialized cells into wandering amoebic cells, thin plate-like blood cells containing the oxygen-transporting molecule hemoglobin, neuronsâ ”cells sending out thousands of tentacles like miniature medusae some hundred thousand times longer than the main body of the cell. The ability of living things to replicate themselves and change their form and structure are truly remarkable abilities. To grasp just how fantastic they are and just how far they transcend anything in the realm of the mechanical, imagine our artifacts endowed with the ability to copy themselves andâ ”to borrow the term from science fictionâ ”to â ˜morphâ ™ themselves into different forms. Imagine televisions and computers that duplicate themselves effortlessly and which can also â ˜morphâ ™ themselves into quite different types of machinesâ ”a television into a microwave cooker, or a computer into helicopter. We are so familiar with the capabilities of life that we take them for granted, failing to see their truly extraordinary characterâ (pp. 84â “85). Kurzweil (2002) responds: â œWe can build (and already are building) â ˜machinesâ ™ that have powers far greater than the sum of their parts by combining the chaotic self-organizing design principles of the natural world with the accelerating powers of our human-initiated technology. The ultimate result will be a formidable combination indeedâ (p. 182). See Kurzweil (1999) and Dyson (1997) for arguments undermining some of the distinctions between technology and nature. Damasio (2003) distinguishes between the components of an airplane and those of a living organism: â œSome of the components of the aircraft are â ˜animatedâ ™â ”slats and flaps, rudder, air brakes, undercarriageâ ”but none of those components is â ˜aliveâ ™ in the biological sense. None of those components is made of cells whose integrity depends on the delivery of oxygen and nutrients to *each* of them. On the contrary, *every* elementary part of our organism, *every* cell in the body, is not just animated but living. Even more dramatically, every cell is an *individual* living organismâ ”an individual creature with a birth date, life cycle, and likely death date. Each cell is a creature that must look after its own life and whose living is dependent upon the instructions of its own genome and the circumstances of its environmentâ ¦There is nothing really equivalent to that living cell in the tons of aluminum, composite alloys, plastic, rubber, and silicone that make up the great Boeing bird. There are miles of electrical wiring, thousands of square feet of composite alloys, and millions of nuts, bolts, and rivets in the skin of the aircraft. It is true that all of these are made of matter, which is made of atoms. So is our human flesh at the level of its microstructure. But the physical matter of the aircraft is not alive, its parts are not made of living cells possessed of a genetic inheritance, a biological destiny, and a life riskâ (pp. 127â “28).

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P. 125: ARTIFICIAL INTELLIGENCE

Franklin (1995) writes: â œAI (Artificial intelligence) is sometimes defined as the art of making machines do things that would otherwise require intelligence if done by a humanâ (p. 11). Kurzweil (1999) writes: â œComputers today exceed human intelligence in a broad variety of intelligent yet narrow domains such as playing chess, diagnosing certain medical conditions, buying and selling stocks, and guiding cruise missiles. Yet human intelligence overall remains far more supple and flexible. Computers are still unable to describe the objects on a crowded kitchen table, write a summary of a movie, tie a pair of shoelaces, tell the difference between a dog and a cat (although this feat, I believe, is becoming feasible today with contemporary neural netsâ ”computer simulations of human neurons), recognize humor, or perform other subtle tasks in which their human creators excelâ (pp. 2â “3). Lanier (2000) writes: â œThe first two or three generations of artificial intelligence researchers took it as a given that blind evolution in itself couldnâ ™t be the whole of the story, and assumed that there were elements that distinguished human mentation from other earthly processes. For instance, humans were thought by many to build abstract representations of the world in their minds, while the processes of evolution neednâ ™t do that. Furthermore, these representations seemed to possess extraordinary qualities like the fearsome and perpetually elusive â ˜common sense.â ™ After decades of failed attempts to build similar abstractions in computers, the field of AI gave up, but without admitting it. Surrender was couched as merely a series of tactical retreats. AI these days is often conceived as more of a craft than a branch of science or engineering. A great many practitioners Iâ ™ve spoken with lately hope to see software evolve but seem to have sunk to an almost postmodern or cynical lack of concern with understanding how these gizmos might actually workâ ¦Finally, there is an empirical point to be made: There has now been over a decade of work worldwide in Darwinian approaches to generating software, and while there have been some fascinating and impressive isolated results, and indeed I enjoy participating in such research, nothing has arisen from the work that would make software in general any betterâ ¦So, while I love Darwin, I wonâ ™t count on him to write codeâ (p. 170). See Johnson (2001) on artificial life.

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P. 126: The Human Brainâ ™s Consistency and Nature

Colburn (1999) writes: â œItâ ™s about three pounds of wrinkled, pinkish-gray matter with the consistency of jellyâ ”and yet, in Emily Dickinsonâ ™s words, â ˜wider than the skyâ ™â (p. 1). He also writes: â œThe human brain has up to 100 billion nerve cells, or neuronsâ ¦Each neuron can form thousands of links, giving a typical brain 100 trillion synapsesâ (p. 2). Grayling (1997) writes: â œIt was a long time before patient observation and scientific method together began to unearth the real mystery: of how a kilogram of pale matter with the consistency of a soft-boiled egg, hidden in a tough casing of bone and without any internal moving parts, can perform all the miracles of consciousness with whichâ ”as their subjectâ ”we are otherwise so familiarâ (p. vi). Nadis (2001) describes the connections between the brainâ ™s neurons as â œan amazingly complex wiring scheme, with more connections than stars in our galaxy, taking shape in an organism that started as a single cellâ (p. 4). Wakker and Richter (2004, p. 30) estimate that â œour galaxy contains about 100 billions stars.â Derrington (2000) writes: â œAccording to one estimate, every cubic millimeter of the brainâ ™s cerebral cortex contains over two miles of connecting neural â ˜wireâ ™â (p. 2).

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P. 127: Images in Brain

Damasio (1999a) writes: â œQuite candidly, this first problem of consciousness is the problem of how we get a â ˜movie-in-the-brain,â ™ provided we realize that in this rough metaphor the movie has as many sensory tracks as our nervous system has sensory portalsâ ”sight, sound, taste, olfaction, touch, inner senses, and so on. From the perspective of neurobiology, solving this first problem consists of discovering how the brain makes neural patterns in its nerve-cell circuits and manages to turn those neural patterns into the explicit mental patterns which constitute the highest level of biological phenomenon, which I like to call imagesâ (p. 9).

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P. 127: Bilingual Brains

See Kim et. al. (1997) and Restak (2001, p. 45).

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P. 127: Many Different Brain Areas Are Used

Blakeslee (2003) writes: â œThe human cortex, where intelligence lies, is simply a lot bigger than that of other creatures given the human bodyâ ™s size. But the size of the body is not everything. One important feature of more complex brains is that they are rich in circuitsâ ”linked cells from various parts of the brain that become active at the same time. Imagine a Christmas tree with millions of lights, each representing a cell group. The thought of dogs would activate a small set of lights. Thinking about a sunset would activate a whole new set of lights with no overlap. Once a thought is complete, all the lights or neurons fall silent, waiting to be called into play in different combinations when new thoughts ariseâ (p. 7).

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P. 128: Limits of Brain Imaging

Stix (2003) writes: â œPictures abound showing yellow and orange splotches against a background of gray matterâ ”a snapshot of where the lightbulb goes on when you move a finger, feel sad, or add two and two. These pictures reveal which areas receive increased oxygen-rich blood flow. But despite pretensions to latter-day phrenology, they remain an abstraction, an imperfect bridge from brain to mindâ (p. 26).

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P. 128: â œEmotionalâ Brain

See LeDoux (1996), in particular, for a description of the thalamus and amygdala working together to provide a â œquick and dirty transmissionâ (p. 166) that allows the brain to start to respond to potential dangers such as a snake on a path.

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P. 129: Neural Tape Delay

Ingram (2000) describes an experiment involving MRI machines and people who were asked to recognize objects: â œBrain activity peaked when the object was recognized and not surprisingly, that peak was reached earlier with objects that had been seen recently. But what was really strange was that peopleâ ™s brains seemed to know when an object had been seen recently before the people themselves knew. The MRI recorded heightened brain activity in response to a familiar object before the person actually said, â ˜I recognize that object; itâ ™s a computer mouse.â ™ This experiment shows that there is much going on in our brains that we are unaware of. It also confirms what other scientists have claimed in other contexts: that consciousness is on some sort of neural tape-delay. We arenâ ™t aware of whatâ ™s happening in our brains, but only what has just happened in our brains, and not much of that either.â Eagleman and Sejnowski (2000) measure the brainâ ™s time lag at 80 milliseconds.

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P. 130: Gut Brain

See Blakeslee (1996).

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P. 130: Signals from the Body to the Brain

See Manier (1999) who describes Damasioâ ™s research involving card games and skin measurements. Damasio (1999a) writes in reference to a patient with locked-in syndrome: â œThe brain lacks the body as a theater for emotional realizationâ (p. 293).

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P. 131: Neurons Communicate at the Synapse with Neurotransmitters

Matthews (2000) writes: â œWe can actually watch the intricate molecular dance that takes place when neurons talk to each other, and we learn more about the control mechanisms involved. Neurons communicate at special junctions, known as synapses, where the transmitting cell releases a chemical signal into the small gap separating it from the receiving cell. When the transmitting neuron is stimulated, channels in its plasma membrane at the synapse open, allowing calcium ions to flood into the cell. This prompts sacks containing chemical neurotransmitters to fuse with the plasma membrane, releasing their contentsâ ”the signalâ ”into the synaptic gap. These neurotransmitters then diffuse across the gap to the neighboring neuron, where they bind to receptors on the plasma membrane and trigger an electrical responseâ (p.835).

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P. 131: Synaptic Change for Memory

See Hall (1998) on the importance of sea snail *Aplysia californica* for research on the role of synaptic change in memory and learning. He quotes Eric Kandel, a biologist who pioneered the molecular study of memory by studying *Aplysia* brains for more than three decades, who declared: â œOne of the wonderful things we began to appreciate is that these goddamn invertebrates can learn anything! I mean, they canâ ™t learn to speak French, but all the things that Pavlov and the behavioral psychologists had talked aboutâ ”what we now call implicit, or non-declarative, forms of memoryâ ”they could do in spadesâ (p. 30). Stevens (1996) comments: â œA cubic millimeter of cortex contains about a billion synapses, so if each synapse could be either strong or weak, then that volume of cortex could store something like 100 megabytes of information. This number cannot be taken seriously for many reasons, but it does indicate the potential power, and thus the great attraction, of the notion that memories can be stored as patterns of synaptic strengthsâ (p. 471).

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p. 131: Memory Is Stored in the Entire Cortex

Fuster (2003) writes: â œAt the same time, the evidence for the consolidation of memory in one store implicates the entire cerebral cortex as such a store and synaptic change in cortical networks as the essence of that consolidation. This view agrees fully with what in cognitive circles is known as the *unitary theory* of memory. There is no need for different neural structures to accommodate different kinds of memory if there is one store that can accommodate all memory, whatever its stage or development or use. What is needed, however, in light of the available physiological and clinical evidence, is a complex topography of cortical networks to accommodate the infinitely diverse contents of memoryâ (p. 121).

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p. 131: Etching Memories in Protein

Damasio (1999b) writes: â œMoreover, the process by which newly learned facts are consolidated in long-term memory goes beyond properly working hippocampi and cerebral cortices. Certain processes must take place, at the level of neurons and molecules, so that the neural circuits are etched, so to speak, with the impressions of a newly learned fact. This etching depends on strengthening or weakening the contacts between neurons, known as synapses. A provocative recent findingâ ¦is that etching the impression requires the synthesis of fresh proteins, which in turn rely on the engagement of specific genes within the neurons charged with supporting the consolidated memoryâ (p. 78). See â œFear Memories Require Protein Synthesis in the Amygdala for Reconsolidation After Retrieval,â by Nader et al. (2000), which reports on research conducted on rats.

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p. 132: Memory for the Short Term

Connors (2002) describes research which found â œthat a single, isolated neuron, when stimulated briefly, could generate sustained increases in its electrical activity that were graded in intensity and readily reversible. In other words, one such neuron could quickly remember (and forget) numerous bits of informationâ ¦Individual neurons are unlikely to go it alone, because memories are distributed across large numbers of neurons. But perhaps intrinsically mnemonic neurons are an essential component of interconnected networks that encode memoriesâ ¦. Without short-term memory, cognition itself crumbles. Disorders of working memory have, for instance, been implicated in such devastating, psychiatric diseases as schizophrenia. If a single-neuron mnemonic mechanism does prove relevant to behavior, it will help us to understand working memoryâ ”and its dysfunctionsâ ”at the molecular levelâ (pp. 133â “34). The quote in the main text on short-term memory is by Connors (2002, p. 133).

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p. 132: New Memories from New Neurons

Macklis (2001) describes the research conducted on the brains of adult rats by a team of neuroscientists: â œThe authors found that a roughly 80 percent reduction in the number of newborn neurons in the adult hippocampus impaired the hippocampus-dependent trace-conditioning memory, but had no effect on another, hippocampus-independent form of memory. Restoring normal levels of neurogenesis in the hippocampus, after the end of the treatment with MAM (a drug which kills proliferating cells), led to the recovery of trace-conditioning memory. The implication is that the normal level of neurogenesis in the hippocampus of adult rats is required for some types of memory that are related to the timing and temporal order of events. By extension, it seems that the new neurons themselves are involved in forming new memoriesâ (p. 315).

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p. 133: Learning and Exercise Increase Survival of New Neurons

Gage (2003) writes: â œOne of the most striking aspects of neurogenesis in the hippocampus is that experience can regulate the rate of cell division, the survival of newborn neurons and their ability to integrate into the existing neural circuitry. Adult mice that are moved from a rather sterile, simple cage to a larger one that has running wheels and toys, for instance, will experience a significant increase in neurogenesisâ ¦Exercising mice in a running wheel is sufficient to nearly double the number of dividing cells in the hippocampus, resulting in a robust increase in new neurons. Intriguingly, regular physical activity such as running can also lift depression in humans, perhaps by activating neurogenesisâ ¦The links between neurogenesis and increased mental activity and exercise also suggest that people might be able to reduce their risk of neural disease and enhance the natural repair processes in their brains by choosing a mentally challenging and physically active lifeâ (p. 34).

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p. 133: Neuronal Networks and How the Brain Learns

See Fuster (2003, pp. xâ “xi) and Vaadia (2000, p. 523) for the quotes in main text.

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p. 133: Brainâ ™s Plasticity

See Holloway (2003) regarding string musicians, dyslexic children and paraplegics.

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p. 134: Views of Self

Gray (2002) writes: â œCognitive science follows Buddhist teachings in viewing the self as a chimera. Our perceptions are fragments, picked out from an unfathomable richnessâ ”but there is no one doing the selecting. Our selves are themselves fragmentaryâ ¦. We labor under an error. We act in the belief that we are all of one piece, but we are able to cope with things only because we are a succession of fragments. We cannot shake off the sense that we are enduring selves, and yet we know not who we areâ (pp. 71â “73). LlinÃ¡s (2001) writes in the same vein: â œâ ˜Iâ ™ has always been the magnificent mystery; I believe, I say, I whatever. But one must understand that there is no such tangible thingâ (p. 127). Varela (1999) describes the self as â œempty of self-natureâ (p. 36). Damasio (quoted in Manier 1999) has another view: â œThe fact that the self exists, illusory or not, requires an explanation. If it is illusory, everything is illusoryâ (p. 3). Damasio (1999a) describes the sense of self as â œthe sense that the images in my mind are mine and formed in my perspectiveâ (p. 76) and proposes that the self is first and foremost a *feeling:* â œthe presence of you is the feeling of what happens when your being is modified by the acts of apprehending somethingâ (p. 10). He also concludes that knowledge is a feeling: â œThe simplest form in which the wordless knowledge emerges mentally is the feeling of knowingâ ”the feeling of what happens when an organism is engaged with the processing of an objectâ ”and that only thereafter can inferences and interpretations begin to occur regarding the feeling of knowing. In a curious way, consciousness begins as the feeling of what happens when we see or hear or touch. Phrased in slightly more precise words, it is a feeling that accompanies the making of any kind of imageâ ”visual, auditory, tactile, visceralâ ”within our living organisms. Placed in the appropriate context, the feeling marks those images as ours and allows us to say, in the proper sense of the terms, that we see or hear or touchâ (p. 26). But Damasio adds that the question of the exact nature of feeling is â œnot entirely answerable at the momentâ (p. 314). The quote in the main text is from McGinn (1999, p. 165).

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p. 135: Difficulty of Reducing Mind to Brain

Shanon (2002) writes: â œI totally reject the possibility that biological accountsâ ”detailed as they may beâ ”can offer viable psychological explanations. Obviously, without a brain, nervous system, and body physiology, we human beings could not accomplish all that we do as cognitive agents. This trivial technical truth, however, should not be confused with theoretical cognitive-psychological claimsâ ¦The situation is analogous to that encountered in music. Admittedly, without a piano, piano music cannot come into existence. However, if one is to understand whatever is pertinent to the understanding of a piano sonata, it is senseless to study only the physics of the piano chords and their acoustics. Rather, one would make use of musically meaningful terms, such as those developed in the theories of melodic progression and musical harmonyâ (p. 34). Nurse (1997) writes: â œThe proper study of mental processes requires consideration of the products of minds and of the interactions between minds. These processes are not easily reducible to cellular and molecular behaviors. For instance, it could be imagined that the recognition of â ˜motherâ ™ by a chick may result in the stimulation of a specific set of ten particular neurons. If these neurons are cultured in a Petri dish and then treated in a way that mimics mother recognition, would these cells in any way be experiencing the concept of mother? This seems particularly absurd. In a similar vein, can the concept of being in love be made explicable in terms of neuronal activity? It is evident that appropriate understanding needs explanation at the appropriate levelâ (p. 657).

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p. 135: Current Limits of Neuroscience

Vaadia (2000, p. 524) compares the current advances of neuroscience to the first flights of the Wright brothers. Stix (2003) writes: â œWe are still nowhere near an understanding of the nature of consciousness. Getting there might require another century, and some neuroscientists and philosophers believe that comprehension of what makes you *you* may always remain unknownâ (p.26). Fuster (2003) writes: â œThe more facts about the brain that we know, the less we feel we know about the cerebral substrate of the mind, which seems to be disappearing in a downward spiral of reductionismâ (p. vii).

CHAPTER 11

P. 137: ORGANIC SIGNS AND BIO-SEMIOTICS

Kampis (1998) writes: â œ*A sign is something that stands for something else.* It is this property of signs, the property of standing for something else, which is responsible for why it seems, at first sight, so controversial to look for signs in the physical universe. Physical objects are what they are, and indeed one doesnâ ™t have to subscribe to metaphysical realism, essentialism, or any other cheap home-brewn laboratory idea of naturalism to see that it would be difficult for them to be something elseâ (p. 268). Kull (1998) writes: â œFor instance, ribosomes in cells are functioning as translators when making new proteins, but they are themselves products of another translation process which synthesizes ribosomes. This makes evident that *organisms are self-reading texts*â ¦Semiosis, more shortly, could be defined as the appearance of a connection between things, which do not have a priori anything in common, in the sense that they do not interact or convert each other through direct physical or chemical processesâ ¦This also means that there exist entities in the world (like â ˜meaningâ ™ of signs) which can influence only living systems and not nonliving ones. Semiotic phenomena do not belong to physical realityâ (pp. 303â “4). Sharov (1998) writes: â œSign processes penetrate the entire body of an organism. The DNA molecule codes the sequence of amino acids in proteins, which in turn may be signals for various kinds of actions at a cell or organism level. Cells communicate with each other using signal molecules (hormones, mediators)â ¦Living organisms have internal self-descriptions written in a DNA form. This description comes from previous generations and summarizes the experience of all ancestors in the art of surviving. Thus, an organism has a dual nature: it stands for itself and it is also a message sent from all previous generations to all future generations. This duality is the essential feature of life which makes biological evolution possible. Differential survival and reproduction of organisms is a semiotic process which incorporates the present into the future. Hoffmeyer characterizes life as survival in a coded form. Messages that provide better recipes for surviving are reproduced together with organisms, whereas messages with poor instructions disappear together with their bearers. Coding is based on conventionality. For example, the correspondence of DNA triplets to amino acids in proteins does not follow from any physical or chemical laws; it is a semiotic correspondenceâ (pp. 404â “5). Witzany (1998) writes: â œUnderstanding the language of nature (nucleic acid language) requires a molecular semiotics that analyses and interprets the molecular interaction processes as sign processes (semioses)â (p. 434).

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p. 137: Genetic â œCodeâ

Witzany (1998) writes: â œThe genetic code which is fixed in DNA and read, copied, and translated in gene expression gains importance as a genetic text only if real sign-users are available to read, copy, and translate it into the amino acid language. This gene expression, along with all the related subprocesses, is neither mechanistic nor mysterious and vitalistic. Rather, it is the result of complex, regulated interactions and highly specific behavior co-ordination between numerous types of enzyme proteins. These enzymes clear the text for reading, implement the copying into the three types of RNA, search the text for superfluous text passages, cut these out, to a certain extent repair damaged sections using rougher and finer techniques (excision and postreplication repair), and complete the entire process of normal gene expression. All enzymatic protein individuals are themselves coded as genetic sequences, yet enzyme proteins themselves always clear genes for reading and thus ensure reproduction of all necessary enzyme proteinsâ (p. 433).

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p. 138: Human â œUniquenessâ

Ingold (1994) writes: â œThe human species is biologically unique. So is every other species on the face of the Earth. This uniqueness, as we have seen, does not consist in some one or more essential attributes that all individuals of the species have in common, and that no individuals of any other species possess. Rather it lies in the present composition of the total pool of genetic traits of which every individual of the species, by virtue of its descent, represents a particular combination. The gene pools of different species may overlap a good deal, especially when they are phylogenetically closeâ ”for example, human beings and chimpanzees have been found to be about 99 per cent the same, geneticallyâ ”but they are never precisely congruent. Moreover the composition of the pool for any species is changing all the time, which is simply another way of saying that it evolves. With regard to species other than our own, these facts are well-established and uncontentious. But when it comes to humans, they meet with obdurate resistanceâ (p. 25). Ingold (1988) writes: â œI endorse the view that the production of artifacts depends on a capacity for symbolic thought unique to *Homo sapiens,* a capacity that is based in the faculty of language; and I believe this has enormous implications for human evolution and human history. Amongst other things, it allows for innovation by deliberate invention rather than accidents of blind variation, for the transmission of design by teaching rather than imitative blind learning, hence for the active acquisition of culture rather than the passive absorption of tradition, which in turn is responsible for the cumulative or progressive growth of knowledge which is surely an undeniable and unique feature of the history of humankind. Howeverâ ”and this is no minor qualificationâ ”we should not be misled by these far-reaching consequences of the symbolic faculty into thinking that it underlies everything that we do. My contention, to the contrary, is that it underlies only a small though highly significant fraction of what we do, whereas for the most part human conduct does not differ all that substantially from the conduct of nonhuman animalsâ (p. 85). Ingold adds: â œAre we equipped for thinking as beavers are for building dams, or as spiders for spinning webs? Assuredly, if you are a human being, there is a certain adaptive advantage in being able to think, just as there is in being able to construct dams or webs if you are a beaver or a spider. Yet this specialization, since it permits the construction of design, rather than the construction of objects (dams or webs) according to a given design, has made us the most generalized and adaptable animals on Earth. We can, if we will, beat the beaver or the spider at its own game, turning to our own account solutions to technical problems already perfected elsewhere in nature through the long process of evolutionary adaptation. All in all, though humans differ but little from other animal species, no more than the latter differ from one another, that difference has mighty consequences for the world we inhabit, since it is a world that, to an ever greater extent, we have made for ourselves, and that confronts us as the artificial product of human activityâ (p. 97).

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P. 138: JAPANESE VIEW OF NATURE

See Kawade (1998, p. 285).

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P. 138: DEFINITIONS OF â œINTELLIGENCEâ

Cohen (1996) writes: â œCreativity and intelligence are the greatest accomplishments of our species. One cannot easily define the qualities that mark out a product of human endeavor as a work of genius. Nonetheless, psychologists have tried to define or quantify the nature of creativity and genius. Just as works of genius are products of their time, so the explanations of creativity and intelligence put forward over the years have reflected prevailing cultural and political concerns and have aroused intense feelings. To this day the study of these higher thought processes continues to be surrounded as much by controversy as mystery. It is probably not very smart to attempt a definition of intelligence. The word has too many meanings and is used to describe too many different types of thinking. The cunning of a detective, the wisdom of a judge and the analytical powers of a scientist are undeniably all forms of intelligence. Moreover, different cultures identify widely divergent mental skills as intelligence: a tribesmanâ ™s proficiency at tracking animals and a philosophers dexterity with abstract concepts are regarded as pinnacles of intelligence in their own societiesâ (pp. 165â “66).

Richardson (2000) writes: â œWe are beginning to see that the existing ground does not offer a firm foundation for anyone seeking to answer the question: â ˜What is intelligence?â ™ Indeed, it is a complex confusion. Most ordinary people seem to know what intelligence is, but it turns out that they arenâ ™t so sure. Most psychologists seem sure about it, but their conviction splinters into disparate fragments when they are asked to define it. IQ testers say they can measure it, but do they know what they are measuring? They say those measured differences reflect genetic differences at least as much as â ˜environmentalâ ™ differences, but how valid have their concepts and methods for demonstrating that actually been? Intelligence is said to be a general principle of animal life that was given a huge boost in the course of human evolution, but of what the difference consists, and why we have it, remains uncertain. This uncertainty is reflected in unanswered questions about what our huge brains are forâ ¦It is clear that the concept of intelligence usually includes deep social and ideological assumptions (of the way that the social world should be, or is naturally) (pp. 22â "23). Fuster (2003) writes: â œAmong the five cognitive functions considered in this monograph, intelligence is the most complex and the most difficult to define. The complexity derives from the close relationships between intelligence and all other four functionsâ ”perception, memory, attention, and language. All four contribute to intelligence, though each does it in a different way and to a varying degree, depending on the individual and the circumstances. The difficulty of defining intelligence derives from the almost infinite variety of its manifestations. Here it is defined as the ability to adjust by reasoning to new changes, to solve new problems, and to create valued new forms of action and expression. This definition is broad enough to reach into the biological roots of cognition, as I have tried to do with every other cognitive function. At the same time, it is broad enough to reach up to the heights of human achievementâ (p. 213). Vertosick (2002), while recognizing that â œthere is no accepted definition of intelligence and no foolproof way of measuring it,â also writes: â œWhen I speak of intelligence, I mean the general ability to store past experiences and to use that acquired knowledge to solve future problems. Iâ ™m not limiting my discussion to human intelligence, which many consider synonymous with intelligence itself. Quite the contrary: I reject the notion that human intelligence is unique in the biological realm. Brains are good at solving a certain class of problems, but they hold no monopoly on problem solving in general. Science now labors under the misguided belief that intelligence is a property found only in hardwired conglomerates like brains and their electronic surrogates, computers. I call this misconception â ˜brain chauvinism,â ™ and I will refute it by showing how all living thingsâ ”even those entirely devoid of nervous systemsâ ”can (and must) use some form of reason to survive. In fact, I believe that intelligence and the living process are one and the same: to live, organisms (or communities of organisms) must absorb information, store it, process it, and develop future strategies based upon it. In other words, to be alive, one must thinkâ (pp. xii, 4).

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P. 140: THERMOSTATS AND INTELLIGENCE

Dennett (1998) writes: â œA thermostat, McCarthy and I claim, is one of the simplest, most rudimentary, least interesting systems that should be included in the class of believersâ ”the class of intentional systems, to use my term. Why? Because it has a rudimentary goal or desire (which is set, dictatorially, by the thermostatâ ™s owner, of course), which it acts on appropriately whenever it believes (thanks to a sensor of one sort or another) that its desire is unfulfilled. Of course you donâ ™t *have* to describe a thermostat in these terms. You can describe it in mechanical terms, or even molecular terms. But what is *theoretically interesting* is that if you want to describe the set of all thermostats (cf. the set of all purchasers), you have to rise to this intentional level. Any particular purchaser can also be described at the molecular level, but what purchasersâ ”or thermostatsâ ”all have in common is a systemic property that is captured *only* at a level that invokes belief talk and desire talk (or their less colorful but equally intentional alternativesâ ”semantic information talk and goal registration talk, for instance) (p. 327). John McCarthy, the inventor of the term *artificial intelligence,* said: â œMy thermostat has three beliefs. My thermostat believes itâ ™s too hot in here, itâ ™s too cold in here, and itâ ™s just right in hereâ (quoted in Searle 1987: 211). Calow (1976) writes: â œMechanists do not always understand that they walk on an extremely narrow tightrope between machine theory and animism. Most machines presuppose the existence of an operator or at least a designer, so it is all too easy to lose balance and fall off the high wire into the net of vitalismâ (p. 9). Grand (2001) writes: â œIs a thermostat conscious because it is â ˜awareâ ™ of its environment (the temperature in the room)? Those who say that it is are debasing the term so much that it is no longer useful, and we would then need a new term to describe what we have, which seems qualitatively rather differentâ (p. 212).

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P. 141: WE DONÂ ™T KNOW HOW MICROORGANISMS PROCESS INFORMATION

The quote in the main text is from Nakagaki (2001a) (p. 767).

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P. 141: COCKROACHES

Rinberg and Davidowitz (2000) write in an article entitled â œDo Cockroaches â ˜Knowâ ™ about Fluid Dynamics?â : â œAnimals use their senses to extract information from the world around them, so they need to be able to gauge the physical properties of their environment in order to build up an accurate perception of it. For example, a bat needs to â ˜-knowâ ™ the velocity of sound to estimate how far away an object is, although input to a sensory system may often exploit more complicated properties than this. Here we measure the response by the wind-sensing system of the American cockroach (*Periplaneta Americana*) to a complex hydrodynamic flow. We find the insectâ ™s interneurons relay crucial information about the windâ ™s spectral properties, which may warn it of approaching predators. The cockroach senses minute air movements using tiny hairs on two posterior appendages called cerci. It can surmise the direction of an attack and scurry away to avoid being eaten. Neural signals from the hairs converge on the terminal abdominal ganglion where the wind information is processed, and are then conveyed further by giant interneurons. Although this system has many of the properties of more complex systems, it remains simple enough to be tractable for studyâ (p. 756).

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p. 142: Just Being Involves Knowledge

Varela (1999) writes: â œThus it seems more and more compelling to look at knowledgeâ ”to understand understandingâ ”in a manner that can only be called post-Cartesian; that is, knowledge appears more and more as being built from small domains composed of microworlds and microidentities. Behavioral repertoires vary throughout the animal kingdom, but what all living cognitive beings seem to have in common is know-how constituted on the basis of the concrete. Thus what we call general and abstract are aggregates of readiness-for-action. In other words, cognitive science is waking up to the simple fact that just *being there,* immediate coping, is far from simple or reflexive. Immediate coping is, in fact, the real â ˜hard work,â ™ since it took the longest evolutionary time to develop. The ability to make intentional, rational analyses during breakdowns appeared only recently and very rapidly in evolutionary termsâ (p. 18).

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p. 142: Building a Machine That Can Walk Is Hard

Brooks (2002) writes: â œJudging by the projects chosen in the early days of AI, intelligence was thought to be best characterized as the things that highly educated male scientists found challenging. Projects included having a computer play chess, carry out integration problems that would be found in a college calculus course, prove mathematical theorems, and solve very complicated word algebra problems. The things that children of four or five years could do effortlessly, such as visually distinguishing between a coffee cup and a chair, or walking around on two legs, or finding their way from their bedroom to the living room were not thought of as activities requiring intelligence. Nor were any aesthetic judgments included in the repertoire of intelligence-based skills. By the eighties most people in AI had realized that these problems were very difficult, and over the twenty years since then, many have come to realize that in fact they are much harder than the former set of problems. Seeing, walking, navigating, and aesthetically judging do not usually take explicit thought, or chains of thought-out reasoning. They just happenâ (pp. 36â “37).

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p. 142: Cell Communication

Scott and Pawson (2000) write: â œThe body functions properly only because cells communicate with one another constantly. Pancreatic cells, for instance, release insulin to tell muscle cells to take up sugar from the blood for energy. Cells of the immune system instruct their cousins to attack invaders, and cells of the nervous system rapidly fire messages to and from the brain. Those messages elicit the right responses only because they are transmitted accurately far into a recipient cell and to the exact molecules able to carry out the directivesâ (p. 55). Wade (2000) writes: â œThe bodyâ ™s 100 trillion cells govern themselves through an exchange of chemical signals. Cells secrete chemical signals to influence the behavior of other cells, and they receive signals through special receptors embedded in their surfacesâ ¦Mr. Haseltine has asserted for several years that the entire communications system of the human body, a set of some 11,000 signaling factors and their receptors, has been identified and captured by Human Genome Sciencesâ (p. 13). Jones (2001) writes: â œCells are continually bombarded with messages of varying importance. Different cells in an organism have different jobs to do, yet they often receive the same molecular e-mails. Cells have to be selective, filtering out the relevant messages from this background buzzâ (p. 1). The quote in the main text is by Downward (2001, p. 759).

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p. 143: Bacteria Communicate

Coghland (2002) writes: â œAntibiotic-resistant superbugs are becoming a massive problem in hospitals worldwide. And if researchers in Britain are right, one reason is that the little devils can send signals through the air, telling other bacteria to turn on their resistance genesâ (p. 12). To date, this airborne signal has not been identified. Pollack (2001) writes: â œ(Research) indicates that bacteria, long thought to be lone operators, have a communication system that lets them determine how many of them they are. The system has been dubbed quorum sensing because it allows the bacteria to determine whether enough of them are present to get down to businessâ ¦Bacteria, it turns out, are like bullies who will not fight unless they are backed up by their gang. An attack by a small number of bacteria would only alert the hostâ ™s immune system to knock them out. So bacteria try to stay under the radar until their numbers are enough to fight the immune systemâ (p. D1). Molecular biologist Bonnie Bassler, who specializes in identifying the molecules which bacteria use to communicate, says: â œThere are 600 species of bacteria on your teeth every morning, and they are in exactly the same structure every single time: this guy is next to that one, is next to that one. It just seemed to us that you canâ ™t do that if the only thing you can detect is yourself. You have to know â ˜otherâ ™â (quoted in Holloway 2004, p. 2).

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P. 144: SALMONELLA SNEAKS INTO CELLS

See Donnenberg (1999) and Centofanti (1996).

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P. 144: INTELLIGENT PROTEINS

Jones (2001) writes: â œItâ ™s surely every scientistâ ™s dream: lab apparatus that does all your experiments for you. Dream onâ ”but look no further than your own body cells for the ultimate in â ˜intelligentâ ™ laboratory ware. Cells are engineered with their own â ˜smartâ ™ apparatus that contains and controls the chemical reactions that keep you alive. A cellâ ™s smart apparatus is made of massive, intricately structured molecules called proteins. Unlike the inert, unrective glassware used in chemistry labs, each piece of protein apparatus is a chemist in its own right, carefully controlling a specific set of chemical reactions inside the cell. Evolution has selected and refined this smart â ˜proteinwareâ ™ to intelligently manage the millions of reactions that drive your metabolismâ ¦Teams of chemists, using the very latest technology to run a reaction sequence are no match for smart proteins. These molecules are â ˜information rich.â ™ Like pieces of specialized software, they only respond to very specific sets of commands. Each protein is specific to the reaction it initiates and controls. Itâ ™s a case of one protein, one structure, one effectâ (p. 1). The quote in the main text is by Miller (1997, p. 328).

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P. 144: PROTEINSâ ™ CAPACITY TO RECOGNIZE

Modlin (2000) writes: â œInnate immunity enables an organism to respond rapidly to invading microorganisms. To do this, the innate immune system uses receptor proteins that can recognize a microbial pathogen by the molecular pattern it displaysâ (p. 659). Kolodner (2000) writes: â œProteins of the MutS family are remarkable sensors of DNA damage. The eukaryotic MSH2-MSH6 complex can detect several types of errors in DNA, with different consequences. For example, mispaired bases that arise as a result of DNA-replication errors are recognized by this complex, and repaired by mismatch repairâ ¦Finally, eukaryotic MutS proteins can recognize chemical damage in DNA, including that caused by some drugs used for chemotherapy. This can activate cell-death pathways rather than DNA repair. Defects in this process result in cellular resistance to these drugs, and the resistance of cancer to chemotherapy. So, if we can unravel how the MutS proteins distinguish between so many types of problematic DNA structure, and communicate specifically with so many downstream pathways, we will not only gain greater insight into a fundamental biological process, but may also learn more about stumbling blocks to the effectiveness of chemotherapy. Several different models for the basic process of mismatch repair have been proposed, all of which conceivably include a â ˜signalingâ ™ element. In bacteria, MutS binds to a mispair and then interacts with MutL, signaling the activation of at least two other proteins. One of these proteins makes a break in the DNA strand containing the incorrect base. The other unwinds this segment of the DNA strand so it can be destroyed. The resulting gap in the strand will then be repairedâ (pp. 687, 689).

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p. 145: Ubiquitin, the Versatile Protein

Marx (2002) writes: â œA small protein called ubiquitin is turning out to be the Clark Kent of cell biology. Like Supermanâ ™s alter ego, ubiquitin has long been regarded as worthy but somewhat dull, a player in the cast of characters that carry out housekeeping functions for the cell. But recent findings are beginning to reveal it as a kind of superhero, performing feats that few suspected. Early work showed that ubiquitin, which was discovered in the mid-1970s, is part of the cellâ ™s janitorial services. It binds to other proteins, tagging them for destruction by a large multiprotein complex called the proteasome. This kiss of death eliminates damaged proteins, an essential job but perhaps not one to catch the eye of Lois Lane. But ubiquitin-mediated protein disposal soon turned out to have a more glamorous role: helping regulate such key cellular processes as the cell division cycle. Now researchers are finding that ubiquitinâ ™s functions go far beyond even these crucial activitiesâ ¦Ubiquitin tagging directs the movement of important proteins in the cell, determining, for example, whether they end up on the cell membrane or in an internal vacuole, where they are destroyed without the proteasomeâ ™s helpâ ¦Other work indicates that ubiquitin and related proteins play direct roles in controlling the machinery that brings about gene expression. The multipurpose molecule also helps regulate the many signaling pathways that control the cellâ ™s responses to environmental and other changesâ (p. 1792).

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p. 147: Jaguars

Angier (2003) writes: â œAs a result of its exceptionally stealthy style, the jaguar has long been one of the least studied members of the feline tribeâ ¦How many cats remain in the wild, and what do they need to prevail? Why are they such masterly climbers and swimmers but such miserable sprinters? How do they manage the swing shift so deftly, at times hunting by day, at times by moonlight?â ¦Jaguars are the top predators of their habitat and, thus, can serve as a so-called indicator or flagship species. If the jaguars are thriving, then chances are that most organisms lower on the neighborhood food chain are faring well, too. If, on the other hand, jaguars start venturing out of their preferred forest cover to attack livestock, then there is probably something out of whack in the woodsâ (p. 7). According to Alan Rabinowitz, head of the jaguar program of the Wildlife Conservation Society: â œNobody has ever managed to film a wild female out with her cubs. Youâ ™ll see the mother. Youâ ™ll see signs of the cubs. But you wonâ ™t see the cubs themselvesâ (quoted in Angier 2003, p. 7).

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About the Author

Jeremy Narby, Ph.D., grew up in Canada and Switzerland, studied history at the University of Canterbury, and received his doctorate in anthropology from Stanford University.