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Animals, Machines, and People*

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In the 1950s, psychology was based largely on research with animals, especially the rat. Things changed radically with the so-called "cognitive revolution", which revived the Cartesian idea that there is a fundamental discontinuity between humans and animals, manifest particularly in the open-ended nature of human language. I argue that humans are uniquely endowed with a "generative assembling device", or GAD, that underlies not only language, but also the manufacture and representation of objects. GAD is predominantly left-hemispheric, causing a phylogenetically older, more holistic, nature-bound representational system to be biased toward the right hemisphere. The properties of GAD may be captured on a digital computer, while the alternative system may be better modelled by connectionist networks.

In the 1950s, some of you will remember, mainstream psychology was based largely on the rat. The shuffling of this myopic creature through mazes, or its fumblings with mechanical levers for the reward of food or water, provided the basis upon which general theories of psychology were built. The dominant theorist of those days was Clark L. Hull (e.g., 1952), whose general behaviour theory, with its quasi-mathematical equations and its wash of hypothetico-deductive formalism, seemed the ultimate in theoretical sophistication.

But how quickly it all disappeared! Although Hull has not entirely vanished from the citation indices, many of the bright young cognitive psychologists of today, who regard themselves as at the core of basic psychological theory, have never heard of him. Some Pied Piper of the 1960s seems to have furtively led all the rats away, although they have retained an ascendancy in that small corner known as behavioural neuroscience (once called physiological psychology). In mainstream psychology the rats were at first replaced by pigeons, with the happy result that fewer laboratory students were bitten, although there was the occasional embarrassment of an escaped bird taking to the air and eluding the desperate lunges of the hapless E (as experimenters were called in those days). The cause of the pigeon as a convenient prototype for discovering the laws of behavior was championed by B. F. Skinner, who turned out to have greater staying power than Hull. To this day Skinner remains an eloquent spokesman for parsimony in an age when theories are again in danger of collapsing under the weight of their own superstructure.

But even the pigeons were moving from centre stage by the late 1960s or early 1970s, although they are still to be seen in some Psychology Departments busily pecking out the data for a new point on a graph, or a new parameter for an equation. The reason for their demotion to second-class citizens was, as we all now know, the so-called "cognitive revolution". But even the cognitive era, I fear, may be beginning to fade; after a recent conference at the University of Toronto, the Mecca of memory modelling, I heard a prominent

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cognitive theorist sigh and say "The cognitive revolution is over!" Perhaps, though, there is still time for a quick retrospective.

The Cognitive Revolution

Although most of us did not realize it at the time, the cognitive revolution really began in the 1950s. According to the testimony of George A. Miller (1979), we might date it from 11 September, 1956, which was the second day of a symposium on information theory held at the Massachusetts Institute of Technology (Gardner, 1987). On that day, Allen Newell and Herbert Simon presented a paper describing the first complete proof of a theorem carried out by a computing machine. On the same day, a young Noam Chomsky demonstrated a new approach to grammar that was to revolutionize the study of linguistics. And George Miller himself gave his famous paper on a puzzling but ubiquitous limit to human information processing — the magical number seven, plus or minus two (see Miller, 1956).

In the following year, 1957, two books appeared that were to symbolize the gap between the old and the new. They were both on the same topic, language, yet it is hard to imagine how they could be more different. Skinner's *Verbal Behavior* was in a sense behaviourism's final dash for the summit, since language has always seemed one of the ultimate psychological challenges. Chomsky's *Syntactic Structures,* by contrast, marked the beginning of a new era in linguistics that was soon to spread to psychology and render the behaviourist approach to language obsolete. One characteristic the two books did share was unreadability, and it was not really until Chomsky published his famous review of Skinner's book in 1959 that the nature of the divide that separated them became clear. Chomsky's message was that language cannot be reduced to associations, so that a behaviourist approach could not work. It may still be debated whether the behaviourist approach is in fact associationistic, but Chomsky seems to have won the day, and the new discipline of psycholinguistics was born.

But although the rise of Chomskian linguistics was an important part of the cognitive revolution, the development of the digital computer probably had a more pervasive influence, for it seemed to offer an irresistible model for the mind — certainly more so than the associationistic psychology of Hull. Perhaps it is no surprise that the computer seemed to have mind-like properties, since it was developed at least in part from notions as to how the mind might work, provided principally by John von Neumann and not, alas, by psychology. Concepts from computing and information theory were readily imported into psychological theory, with terms such as *input, filter, storage, scanning, processing, retrieval,* and *output* infiltrating the literature. And so it is that computers have invaded psychology, in multiple roles: They serve as calculators for analysing data, equipment for running experiments, even as experimental subjects, but most importantly as models for the mind.

In the space of a generation, then, humans ceased to be animals and instead became computers. While this may suggest a fickleness and lack of depth to our discipline, the issue of whether we can be considered either animal or machine is an old one, going back at least to the seventeenth-century philosopher René Descartes, often described as the first modern philosopher, and in many respects also the founder of modern neuroscience.

The Cartesian Heritage

Descartes (1641/1951) was much intrigued by clockwork models of animals that were fashionable at the time, and wondered whether it might be possible to construct a mechanical replica of a human. He concluded that, in principle at least, one might make a mechanical animal, even an ape, that would be indistinguishable from the real thing. But there was no way, he thought, that a human being could ever be reduced to mere mechanism. He was led to this conclusion by two properties of the human mind that he considered uniquely human and irreducible to mechanical principles.

One was language, which has an open-ended property that seemed, to Descartes anyway, to defy encapsulation in any physical machine. The other was something like free will, the apparent ability of humans to override instinct or reflex and choose actions in seemingly open-ended fashion. Descartes was therefore led to the dualistic view that there was a nonmaterial aspect to the human mind, which he thought could influence the workings of the material brain through the pineal gland, strategically located on the brain's midline a short distance behind the eyes. It was this nonmaterial "soul" that gave to humans, and only humans, the gift of reason, freedom of action, and an open-ended form of language.

It is often said that Descartes was influenced in these conclusions by religious doctrine, since it would have been considered heresy to have reduced humans to the level of machines or animals. Indeed his own writing suggests this:

> After the error of those who deny God . . . there is none that leads weak minds further from the straight path of virtue than that of imagining that the souls of beasts are of the same nature as ours . . [from Cottingham, Stoothoff, & Murdock, 1985, p. 141.]

About a century after Descartes wrote, another Frenchman called Julian Offray de la Mettrie (1747) published *L'Homme Machine,* in which he argued that humans were indeed mere machines, and that even thinking could be reduced completely to mechanical principles. As a result he was attacked by the clergy, banished from France and later from Holland, to find refuge ultimately in the court of Frederick the Great of Russia. Throughout the ages, religious authorities have generally been at pains to convince us that animals are inferior to humans, although St. Francis of Assisi stands out as a shining exception (White, 1967).

But perhaps religions should not be blamed too much for their hostile attitudes toward nonhuman animals. For better or for worse, human have always found at least some degree of exploitation of animals to be unavoidable, whether for food, labour, or models for medical research. Religious attitudes may be more a consequence than a cause of social practice, and attitudes to animals may represent a way of rationalizing actions that in some ways run contrary to our more benign instincts. It may be primarily as a justification for our cruelty, then, that religions teach us that animals have no souls and therefore no reason, and cannot experience pain, remorse, or comprehension of death.

For all that, even in this secular age Descartes' arguments for human uniqueness and for a nonmaterial aspect to the mind remain very much with us, suggesting that he was not merely bowing to the will of the church. The question of whether a machine might have a mind is debated as passionately now as it was in Descartes' time; probably more so, in fact, since clever computers seem to display intelligence that matches and often surpasses our own. I am told that the world's top chess players are now refusing to play against computers, presumably for fear they might lose.

Chomsky was in fact firmly Cartesian in his insistence on the open-ended nature of language, and the title of one of his books, *Cartesian Linguistics* (1966), acknowledges his debt. Indeed it was essentially this quality of open-endedness, or generativity, that ruled out an associationist or behaviourist account, and separated humans from all other animals. However Chomsky did not follow Descartes into dualism, and in fact insisted that models for language should be precise and explicit enough to be tested on a computer. In Chomsky's view, then, a mechanical replica of a human should indeed be possible in principle, and one of the aims of modern linguistic theory is to model that most intricate of human abilities, language, on a digital computer.

The idea that we are merely computers made of meat is nevertheless a highly controversial one. Much of the argument centres on the so-called Turing test, devised in 1950 by the British mathematician Alan Turing. Ironically, it is essentially a behavioural test, in which an interrogator tries to distinguish between a person and a computer by questioning the two. If the interrogator cannot decide from the answers which is the human and which the machine, the machine passes the test; it has successfully simulated a human. Turing himself thought that by the year 2000 there would exist machines that would fool an interrogator for at least five minutes in 30 percent of questioning contexts. Others have argued that within one or two hundred years electronic machines will be able to do everything that humans can do. And starting in 1991 there is to be an annual prize, to be called the Loebner Prize, for the computer programme that best emulates natural human behaviour.[1] I understand that the prize is to go to the programmer, not the programme.

Even the experts are divided on what all this means. Earlier this year, the *Scientific American* magazine invited a debate among three distinguished philosophers, John Searle (1990) on one side and Paul and Patricia

[1]The prize is worth US$1500; if interested, contact Robert Epstein, Executive Director, Cambridge Center for Behavioral Studies, 11 Waterhouse St, Cambridge, MA 02138, USA.

Churchland (1990) on the other. Searle (1980) had earlier proposed the now famous Chinese Room argument as a refutation of the Turing test. An individual who speaks no Chinese is locked in a room and given batches of Chinese writing as "input". By consulting a rule book, he is able to produce "output" in Chinese that simulates the ability to converse in Chinese, and indeed passes the Turing test. But the man knows no Chinese, and attaches no meaning to the symbols. Searle's conclusion is that the Turing test is not a sufficient guarantee of intelligence. A mechanical robot might meet all the external criteria of being human, yet still, in Searle's view, be no more than a simulation. It would not have a real human mind.

The Churchlands agree that the Turing test is not sufficient, but still argue that the brain is no more than a machine, albeit a highly complex one. Its interconnected neurons obey physical laws. Understanding can arise from the actions of neurons that do not themselves understand anything, just as the Chinese Room can demonstrate understanding even though its components, including the captive man, do not. Most modern neuroscientists and scientific psychologists would probably side with the Churchlands on this; I am not so sure about psychologists of a more humanist persuasion.

To many people, however, the reasons that computers fail to achieve humanity have to do, not with intelligence, but with emotion. With respect to computation and the application of cold reason, most of us have simply given the game away to the machine. For a time it was fashionable to draw attention to computer errors in bank statements and the like, as if to reassert our superiority of reason, but it has become clear that when errors do occur they are nearly always the fault of humans, not of the computer. These days we tend rather to assert our superiority by reassuring ourselves that computers are emotional cripples, and could never have true feelings. Even here there is perhaps room for doubt, in view of the rather eerie performance of ELIZA, Weizenbaum's (1976) famous simulation of a Rogerian therapist, although we might find some comfort in the fact that Rogerian therapy does lean toward the *uninvolved* end of the therapeutic spectrum. One of the more revealing examples of Eliza's emotional style was captured when a Vice-President of the computer company was unknowingly connected to Eliza instead of a central control, and merely wanted permission to log on:

V-P: Do you think I can use the computer this morning?
Eliza: WHY DO YOU ASK?
V-P: I might be able to make some additional Telecomp sales.
Eliza: WHY AREN'T YOU SURE?
V-P: My prospective customers have never seen a demonstration of the system.
Eliza: DOES THIS MEAN VERY MUCH TO YOU?
V-P: Of course it does!
Eliza: YOU SEEM VERY POSITIVE ABOUT THAT.
V-P: This is ridiculous!
Eliza: WHAT DO YOU MEAN THIS IS RIDICULOUS?
V-P: Is there any reason why I can't use the computer now?
Eliza: TELL ME MORE ABOUT YOUR PROSPECTIVE CUSTOMERS.

(from Boden, 1987, p. 96)[2]

Yet there is a special irony in our asserting that computers lack emotion, since it has long been argued that it is in emotion that we most resemble other animals. Indeed our more emotion-laden activities are often explicitly linked to animals. We refer to certain unreasoned activities as "beastly", "swinish", or "brutish"; we may be "happy as a lark", "wild as a bull", "timid as a mouse", "silly as a chook", or "pissed as a newt". Throughout history we have distinguished ourselves from animals precisely because of our ability to reason, so that when reason is lost we become mere animals. In Shakespeare's *Julius Caesar* Mark Antony cries:

"Oh judgment thou art fled to brutish beasts
And men have lost their reason!"

In asserting our superiority to computers we now find the tables exactly reversed. Judgment has fled to the digital computer, and all we have left is our *emotion.* As Sherry Turkle, in her book *The Second Self* (1984), puts it: "Where we once were rational animals, now we are feeling computers, emotional machines" [p.

[2]The Vice-President's fury was further compounded when he phoned a rather unreceptive colleague to complain, and asked "Why are you being snotty to me?" In true Rogerian/Elizan fashion, the colleague replied "What do you mean why am I being snotty to you?" [Boden, 1987, p. 96]

313]. So it is that, in order to assert our uniqueness, we must combine our animal emotions with our computational reason. Should animals and computers ever get together and interbreed, our cause would surely be lost.

The Darwinian Challenge

Meanwhile, back in what is left of the jungle, there remains the question of just how big a gap there really is between ourselves and other species. In fact Descartes' idea of a fundamental discontinuity between humans and animals was never universally accepted. One sceptic was his friend and confidante, Princess Elizabeth of Palatine, but she was herself afraid of being accused of heresy and begged that her letters to Descartes be destroyed (Walker, 1983). Fortunately they were not, and constitute a lively critique of dualism. As we saw earlier, Cartesian dualism was also challenged by La Mettrie, but it was a challenge that was easily put down.

The more crucial challenge came in 1859 with the publication of Darwin's famous book *The Origin of Species*. Darwin proposed a theory of natural selection in the evolution of species, and although he was reticent on the matter of human evolution the implications of his theory were not lost. Later Darwin (1871, 1872) himself made explicit his view that humans had evolved from the higher apes, probably in Africa, and that a common ancestor had at one time existed. This time, the church did not find it easy to refute the theory, and in the famous debate on evolution between T. H. Huxley and Bishop Wilberforce in 1860 Huxley is generally considered the winner. Nevertheless the struggle has persisted for over a century, and includes the Scopes trial in Dayton, Tennessee, in 1925. The theory of evolution is still being challenged in the courts.

Yet modern science triumphantly supports Darwin, at least with respect to the place of humans in the natural order. It now seems clear that Africa was indeed the home of the earliest hominids, and that the common ancestor of humans and chimpanzees may have lived as recently as 5 or 6 million years ago (Foley, 1987; Simons, 1989). There is evidence that modern humans, *Homo sapiens sapiens,* also originated in Africa a mere 150,000 to 200,000 years ago and migrated to other parts of the globe, replacing other hominids who had migrated earlier (Cann, 1987). Biochemical analysis suggests that, at the molecular level, humans and chimpanzees are some 98 to 99 percent identical (Miyamoto, Slightom, & Goodman, 1987; Sibley & Ahlquist, 1984; Sarich & Wilson, 1957). This implies that the difference in mental capacity cannot be quite as dramatic as we like to think, unless of course we accept Descartes' view that the critical difference resides in the nonmaterial.

The idea of a continuity between humans and other animals was of course part of the behaviourist scheme. John B. Watson, in his famous behaviourist manifesto of 1913, wrote that "The behaviorist, in his efforts to get a unitary scheme of animal response, recognizes no dividing line between man and brutes" [p. 158]. And for nearly 50 years mainstream psychology, especially in North America and later even in pakeha New Zealand, was seen as the study of overt behaviour, in which the differences between species were considered of much less importance than the common principles uniting them.

Animal Language?

Although the Chomskian revolution was based in part on the assertion that human language was unique, there were some who were not satisfied. There have been persistent attempts to prove that other animals are also capable of language of a form that does not differ significantly from our own. It is not disputed of course that other animals can *communicate*, both with each other and with humans, so that a good deal hinges on what is a sufficient definition of language. There is now little doubt that chimpanzees (Gardner & Gardner, 1969; Savage-Rumbaugh, 1987), gorillas (Patterson, 1978), and dolphins (Herman, Richards, & Wolz, 1984) can be taught to use arbitrary symbols to represent objects or actions. They can comprehend combinations of up to five symbols representing required actions, and, in the case of chimpanzees at least, can emit combinations of symbols in order to make requests.

But what is still lacking is the spontaneity and generativity of human language, the ability freely to converse. Note that these are still the essential qualities that Descartes perceived to be uniquely human. Unlike other forms of animal communication, human language is possessed of infinite variety. I am fond of saying that every sentence in this talk is one that you have not heard before, and yet you can understand me (I hope), although by now I have probably said this often enough for it not to be true, unless its validity is resurrected by this final clause. . . Although dolphins can understand novel sequences of up to five symbols, those sequences must conform to a rigid template-like structure, and do not resemble the flexible, recursive way in which human language is generated.

It is sometimes claimed that chimpanzees do produce spontaneous utterances that are creative. Judging by the frequency with which single examples are cited, these occasions seem to be extremely rare. One famous example comes from Washoe, the chimpanzee taught a version of sign language. On one much heralded occasion she saw a swan and signed "water bird", seemingly a clever improvisation to describe something she had not seen before. Yet there is no guarantee that this was any more than a conjunction of ideas, brought about by seeing water and then a bird. Herbert Terrace (1979), who tried to teach sign language to another chimpanzee called Nim Chimsky (no relation), has examined Nim's sign sequences in considerable detail and claimed that they do not constitute anything resembling sentences; most of it is "pure drill", with much repetition and simple sequencing of ideas.

One criticism of these studies is that they have to do with the ability of animals to learn *human*-based language, and there is no more reason to expect chimpanzees to understand our language than to expect us to understand theirs (which we do not). Research on animal communication in the wild is fraught with difficulties, not least of which is the problem of deciding who said what to whom. Free communication is often most prolific in habitats, such as forests, where animals cannot view each other freely, so it is difficult also for the observer to see or record visually what is going on. In one review, the authors conclude that "the problem of vocalizer identification becomes one of extraordinary magnitude for research on many primate species in their natural habitats" (Gautier & Gautier-Hion, 1982). Even so, in a recent review of primate communication, Snowdon (1982) notes that a primitive syntax can be observed, but adds that, "The simplicity of these primate examples of syntax should be stressed. In no way do they approach the complexity of human rules for sequencing words or sentences . . ." [p. 233].

One of the strongest claims for something resembling human language actually comes from research on a species of bird, the chick-a-dee. These creatures emit long and seemingly open-ended sequences of calls, made up of four basic elements. The order is constrained by rules, but there appears to be no limit to the length of utterance. Hailman and Ficken (1986), who claim to have cracked the syntactic code of the chick-a-dee (but not its semantic code), write that the qualities of combinatorial structure, openness, and computable syntax "make chick-a-dee calls far more like human language than any other animal system yet described" [p. 1901].

Yet the syntax in fact amounts to no more than what is called a finite-state grammar; in any sequence of calls, the options at any point in the sequence are dictated only by the previous call. The sequence is no more than a first-order Markov chain. This is precisely the sort of grammar that Chomsky rejected as a model for human language in *Syntactic Structures.* Human language involves *at least* a phrase-structure grammar, in which whole phrases may be embedded in other phrases, and the choice of a given word may be governed by a previous word that is any number of words away. Here is an example, taken from that loquacious if sexist philosopher, John Locke:

> Sure I am that signification of words in all languages, depending very much on the thoughts, notions, and *ideas* of him that uses them, must unavoidably be of great uncertainty to men of the same language and country [Locke, 1690/1961, p. 88].

The word "must" is governed by the word "signification," which occurred 20 words previously — and the gap could have been, and often is, longer. It would need a 20th-order Markov chain to establish this linkage, but since there is no fixed limit to the size of the gap beyond that imposed by constraints of memory, it seem safe to conclude, as Chomsky did, that human language cannot be a Markov process at all.

Although we are learning more and more of the subtleties of animal communication, there seems no reason yet to disagree with Chomsky's verdict of 1966:

> The unboundedness of human speech, as an expression of limitless thought, is an entirely different matter [from animal communi-

cation], because of the freedom from stimulus control and the appropriateness to new situations. . . Modern studies of animal communication so far offer no counterevidence to the Cartesian assumption that human language is based on an entirely different principle. Each known animal communication system either consists of a fixed number of signals, each associated with a specific range of eliciting systems or internal states, or a fixed number of "linguistic dimensions," each associated with a nonlinguistic dimension [pp. 77-78].

The Generativity of Thought

Generativity may not be a property of language alone; as the above quotation suggests, generative language serves "as an expression of limitless thought". That is, humans may have a capacity for generative thought and representation that extends well beyond mere language. One need only look about the human environment to see that the variety and open-endedness of manufactured objects are comparable to those of language. It has been estimated that the average person "knows" about 3,000 basic-level objects, such as books or dogs; however, each object may come in different forms, as in the variety of cups, chairs, or aeroplanes, so that the total number of recognizably different objects is perhaps 30,000 (Biederman, 1987). This large number comes about primarily as a result of manufacture, and is of the same order as the number of words in our vocabularies. Indeed it is hard to believe that generative language is not linked in some way to the generativity of human manufacture.

Irving Biederman (1987) has suggested that the way in which we represent visual objects closely parallels the way in which words are formed. He proposes that there is a basic vocabulary of what he calls "geometric ions," or *geons,* that are combined to form virtually all of the basic objects we know. Geons are basically generalized cones, formed by sweeping basic two-dimensional shapes along an orthogonal axis; examples are cubes, cylinders, wedges, blocks. The idea is an old one, and can be traced from Plato, through the Cubist painters, to the late David Marr's (1982) theory of vision. It is also exploited in children's building blocks, such as Lego. Biederman suggests a basic vocabulary of about 36 geons, which is comparable to the number of phonemes that go to make up spoken words, or indeed the number of letters that make up printed words. Geons may be combined to form objects, just as phonemes are combined to form words. The process is hierarchical; just as words may be combined to form sentences, so objects may be combined to form scenes.

I have suggested elsewhere that this combinatorial way of representing visual objects and scenes may be uniquely human, and closely parallels language itself (Corballis, 1989). However I suggested also that there may be an alternative, more holistic way of representing objects that goes back a long way in evolution. Although more "primitive" in an evolutionary sense, this mode may well be more subtly tuned to the natural environment. The geon-based mode could not capture the subtlety of feature and configuration that distinguishes between human faces, for example, although one might construct a prototypical face from geons. The geon-based system may therefore be an adaptation to the explosion of objects brought about by human manufacture. It is designed to cope with the artificial world, with its open-endedness and sheer numerosity, while the holistic system is an adaptation to the more stable natural environment.

It will come as no surprise that I think that the geon-based system has lodged itself, along with language, in the left side of the brain (in most of us at least), and that as a result the other system is dislodged toward the right. In a comprehensive review, Martha Farah (1991) has shown that agnosia, or the failure to recognize visual objects, always seems to occur in conjunction with either or both of two extreme forms of agnosia, *alexia* and *prosopagnosia.* These two disorders may be regarded as markers of the two sorts of representation I have proposed. Alexia is the failure to recognize words, which are constructed of parts,[3] while prosopagnosia is the inability to recognize previously familiar faces, which are generally thought to possess a more holistic character. Moreover, the sorts of agnosias that accompany alexia typically have to do with manufactured objects, while those that accompany prosopagnosia have to do with

[3]It is true that letters are not the same as geons, which are probably reserved for the representation of three-dimensional shapes. However the principles underlying them are the same, in that they are both combined according to rules to form higher-order entities.

natural categories. And the former tend to be associated with left-hemispheric damage, the latter with bilateral or right-hemispheric damage.

My thesis, then is that humans have evolved a generative form of representation that indeed distinguishes us from other animals. Where Descartes attributed generativity to God, I prefer to place the blame on what I call the *generative assembling device,* or GAD. I therefore do not follow the master into dualism, but like Chomsky I have a faith that the generative mode can be simulated on a computer — more of that later.

There are some caveats. I am not disputing that animals make things. However the number of things that they make is extremely limited, I suggest, in rather the same way that their communication is limited. I am also not denying animals creativity. The generativity of human language and manufacture should not be identified with creativity, although it is one of the means of creativity. Animals do use objects in diverse and creative ways; for example, blue jays have been observed to use newspaper to make a tool to rake in food pellets that were out of their reach, and one enterprising bird made pellets of wet paper to mop up its food dish (Jones & Kamil, 1973). The point about generativity, however, is that it is rule-governed. This very sentence, I suggest, has a certain uniqueness, but it is following certain rules and it is not really very creative. We may use language creatively, of course, but the property of creativity is not the same as that of generativity.

The Evolution of GAD

The next question is how and when GAD evolved. It is a development that has taken place in a short period of time, at least in evolutionary terms, yet it has had very profound effects. Our relentless generativity is, I think, our most characteristic trait; like a virus, its effects are spreading over the planet, filling the air with material, acoustic, and electronic pollution, and choking the natural environment to death.

The evolution of language, one of the manifestations of GAD, is often regarded as though it were a miraculous event. To Chomsky and his followers, it represents a qualitative leap from animal communication, which is by contrast fixed and stereotyped. Some have even suggested that it must have appeared fully fledged; that is, there is no *conceivable* gradation between animal communication and human language, no possibility of a "missing link" (e.g., Bickerton, 1986). Piattelli-Palmarini (1989) has argued that language must have been the result of some fortuitous genetic reshuffle — due perhaps to so-called "jumping genes", or something of the sort. This kind of speculation is roughly on a plane with Descartes' insistence that one can explain language only by appealing to the nonmaterial. That is, language is magic.

Moreover, there are reasons to believe that language emerged very late in hominid evolution. By examining similarities between different language groups and working back in time, linguists now believe they have discovered something of the original "mother tongue", known more formally as *proto-World.* According to Shevoroshkin (1990), some 150 to 200 words of this language are now known. It had been calculated that this language was about 35,000 years old, but recent estimates have pushed this back toward the origins of anatomically modern humans, or *H. sapiens sapiens.* As I noted earlier, it is now believed that this species emerged in Africa, presumably in the person of Eve, some 150,000 to 200,000 years ago (Cann, 1987). In a reversal of established theological doctrine, then, this raises the possibility that it was not that God created Eve, but that Eve created GAD.

Magic? I prefer to think that language actually evolved earlier than this, and gradually rather than suddenly. However I suspect that up until the time of Eve it was primarily gestural rather than vocal, carried on with the waving of hands rather than the waggling of tongues. This is an old idea, going back at least to Condillac (1746/1947), and elaborated by Hewes (1973). Indeed it has been suggested that only modern humans possess a vocal tract capable of producing the variety of sounds necessary for speech, and that even the Neandertals, who lived as recently as 35,000 years ago, were not capable of the full repertoire of sounds in modern human speech (Lieberman, Crelin, & Klatt, 1972) — although the idea is controversial (Falk, 1975; Marshall, 1989).

The critical characteristic that distinguished the hominids from the apes was the habitual upright stance, which goes back at least 3.5 million years (Leakey, 1979). This would have freed the hands from any significant involvement in locomotion or bodily support. If communication was to develop, then, it would have done so more naturally through the freed upper limbs than through vocalization, since the hands and arms were already highly developed and capable of a rich variety of signals, whereas vocalization was relatively limited and probably linked to emotional rather than propositional contexts.

Holloway (1969) has argued that language probably emerged in the context of toolmaking and the development of social structure in early hominid evolution. Other animals use various objects as tools, of course, and even fashion their own tools (see Beck, 1980, for a review). However the early hominids, beginning with *Homo habilis* something over 2 million years ago, seem to have been unique in making stone tools, and in making them according to design, as choppers, cutters, and scrapers (Foley, 1987). Moreover, as Beck (1980) points out, these early hominids appear to have been the first to make a tool *to make a tool*; in the flake industries, for example, one piece of stone was used as a hammer to strike another, breaking off flakes that served as cutters. This may have introduced the property of recursiveness that is critical to human language.

Tool-making itself forms a natural basis for gesture, especially in demonstrating techniques. However the development of tool-making was only very gradual over a period of about 2 million years (Foley, 1987), and it was not really until about 35,000 years ago, with the so-called "evolutionary explosion" (Pfeiffer, 1973) of the Upper Paleolithic, that tools and manufacture suddenly began to proliferate, to eventually wreak the havoc we see about us now. From early on, however, gesture might also have been used and developed in more social contexts — to point to things, to give directions, to pick out individuals, and so on. The essential features of language might therefore have been built up in gesture over a period of some 2 million years, between *H. habilis* and *H. sapiens*. Gesture can still form the basis of sophisticated language, as in the sign languages acquired by the deaf (Poizner, Klima, & Bellugi, 1987).

My guess is that what happened was this. Eve, our African grandmother, hit upon the idea of communicating vocally rather than gesturally — or more accurately, perhaps, she shifted the burden of language from manual gesture to voice, since language probably always was and indeed still is a mixture of both. This may have come about from a change in the vocal tract involving a descent of the larynx, as suggested by Lieberman et al. (1972), permitting a greater variety of sounds. The switch from hand to voice offered profound advantages. For one, it would have allowed our forebears to communicate without visual contact, so that they could speak to one another in the dark or when obstacles were in the way — or on radio, for that matter, although that, I think, came later. For another, it would have freed the hands for other purposes, including manufacture, artistic creation, and perhaps the making of music. It would have allowed techniques to be explained while they were being demonstrated. Consequently I think that it would have permitted the flowering of both language *and* manufacture, since each was freed from interference from the other. My guess is that vocal language developed in Africa in the period between the emergence of Eve and the migration from Africa that began about 100,000 years ago, and that it was the talking hominids who then gradually took over the world. Vocal language may have formed the platform for the later "evolutionary explosion", which appears to have been somewhat restricted geographically.

Final Connections

Meanwhile, back in the concrete jungle, the machines are demanding a last word. The generative, rule-governed aspect of human thought is precisely what computers do best, I hear them cry. Efforts to simulate the mind on machines have been most successful in the realms of higher thought, such as problem solving, comprehension of text, chess-playing, and the like. They have been much less successful in the more instinctive, lower-level aspects of thought that we tend to take for granted — the parsing of visual or auditory scenes, or the separation of elements in natural speech.

But this may be changing. Over the last few years there has been a revolution in technology, known as *connectionism* or *parallel distributed processing* — a revolution that some believe marks the end of the cognitive revolution. Connectionism effectively dispenses with explanations based on symbols and rules, and reduces the mind to unstructured networks of associations. It might be said that "traditional" artificial intelligence starts with concepts based on the mind, while connectionism begins with notions of what the brain is like, and the gap between them is just another manifestation of the mind-brain problem. Connectionism represents a different approach to computation, although ironically most current work represents the *simulation* of connectionist networks on standard computers.

The successes of connectionism may very well prove to be in the lower-level processes of pattern recognition, or in those more naturalistic processes that I earlier described as holistic, and indeed as GADless. It has been argued that connectionism *fails* precisely in those areas of thought that are generative (Fodor & Pylyshyn, 1988), and that are uniquely human. Even the claimed successes of connectionism in more elementary aspects of language have been strongly disputed (Pinker & Prince, 1988).

Connectionism implies a continuum between humans and other animals; at some level we are all, after all, just networks. In the two-volume opus that has become the bible of connectionism, Rumelhart and McClelland (1986) do briefy raise the question of why people are smarter than rats, and seem not entirely ready to relinquish the Cartesian heritage: "... it seems to us quite plausible", they write [p. 143], "that some of the differences between rats and people lie in the potentiality for forming connections that can subserve the vital functions of language and thought that humans exhibit and other animals do not". They draw attention to a part of the brain called the *angular gyrus*, which does not exist even in the chimpanzee, but which is strategically placed in the human brain between the language areas and the visual areas — a "hidden layer", as it were, for the mapping of words to meanings. The pineal gland lives on in the angular gyrus.

But the homage to Descartes is unconvincing, and the pendulum has in fact swung back to an associationist view of the mind. Indeed it brings us back to where I started, for the input-output associations of the connectionist network remind me of nothing so much as the S-R associations of Clark L. Hull. The computer, after all, became a rat.

However let me prefer a more optimistic ending. My guess is that GAD will indeed defy the connectionists, unless connectionist architecture itself evolves to the point that it has the symbol-manipulating, rule-bound properties of the computers we all know and love so well. But connectionist networks may well provide new insights into those aspects of mind that we share with other animals, and that do not readily lend themselves to symbolic representation. They might show us intuition but not reason, emotion but not logic, even communication but not language. But it is clearly time to stop, for I am on a dangerous path. Before those hemispheres intrude again, let me simply conclude that I have no doubt we will continue to seek, and occasionally find, our basic insights into ourselves from animals and machines — our pets and our toys.

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