Mirror neurons and imitation learning as the driving force behind "the great leap forward" in human evolution

by V. S. Ramachandran

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The discovery of mirror neurons in the frontal lobes of monkeys, and their potential relevance to human brain evolution — which I speculate on in this essay — is the single most important unreported (or at least, unpublicized) story of the decade. I predict that mirror neurons will do for psychology what DNA did for biology: they will provide a unifying framework and help explain a host of mental abilities that have hitherto remained mysterious and inaccessible to experiments.

There are many puzzling questions about the evolution of the human mind and brain:

1) The hominid brain reached almost its present size — and perhaps even its present intellectual capacity about 250,000 years ago. Yet many of the attributes we regard as uniquely human appeared only much later. Why? What was the brain doing during the long incubation period? Why did it have all this latent potential for tool use, fire, art, music and perhaps even language that blossomed only considerably later? How did these latent abilities emerge, given that natural selection can only select expressed abilities, not latent ones? I shall call this "Wallace's problem," after the Victorian naturalist Alfred Russell Wallace who first proposed it.

2) Crude "Oldawan" tools — made by just a few blows to a core stone to create an irregular edge — emerged 2.4 million ago and were probably made by Homo habilis whose brain size was half way (700 cc) between modern humans (1300) and chimps (400). After another million years of evolutionary stasis aesthetically pleasing symmetrical tools began to appear associated with a standardization of production technique and artefact form. These required switching from a hard hammer to a soft (wooden?) hammer while the tool was being made, in order to ensure a smooth rather than jagged, irregular edge. And lastly, the invention of stereotyped assembly line tools (sophisticated symmetrical bifacial tools) that were hafted to a handle, took place only 200,000 years ago. Why was the evolution of the human mind punctuated by these relatively sudden upheavals of technological change?

3) Why the sudden explosion (often called the "great leap") in technological sophistication, widespread cave art, clothes, stereotyped dwellings, etc. around 40 thousand years ago, even though the brain had achieved its present modern size almost a million years earlier?

4) Did language appear completely out of the blue as suggested by Chomsky? Or did it

evolve from a more primitive gestural language that was already in place?

5) Humans are often called the "Machiavellian primate" referring to our ability to "read minds" in order to predict other peoples' behaviour and outsmart them. Why are apes and humans so good at reading other individuals' intentions? Do higher primates have a specialised brain centre or module for generating a "theory of other minds" as proposed by Nick Humphrey and Simon Baron-Cohen? If so, where is this circuit and how and when did it evolve?

The solution to many of these riddles comes from an unlikely source: The study of single neurons in the brains of monkeys. I suggest that the questions become less puzzling when you consider Giaccamo Rizzollati's recent discovery of "mirror neurons" in the ventral pre-motor area of monkeys. This cluster of neurons, I argue, holds the key to understanding many enigmatic aspects of human evolution. Rizzollati and Arbib have already pointed out the relevance of their discovery to language evolution. But I believe the significance of their findings for understanding other equally important aspects of human evolution has been largely overlooked. This, in my view, is the most important unreported "story" in the last decade.

The emergence of language

UNLIKE MANY other human traits such as humour, art, dancing or music the survival value of language is obvious — it helps us communicate our thoughts and intentions. But the question of how such an extraordinary ability might have actually evolved has puzzled biologists, psychologists and philosophers at least since the time of Charles Darwin. The problem is that the human vocal apparatus is vastly more sophisticated than that of any ape but without the correspondingly sophisticated language areas in the brain the vocal equipment alone would be useless. So how did these two mechanisms with so many sophisticated interlocking parts evolve in tandem? Following Darwin's lead I suggest that our vocal equipment and our remarkable ability to modulate voice evolved mainly for producing emotional calls and musical sounds during courtship ("crooning a tune"). Once that evolved then the brain — especially the left hemisphere — could evolve language.

But a bigger puzzle remains. Is language mediated by a sophisticated and highly specialised "language organ" that is unique to humans and emerged completely out of the blue as suggested by Chomsky? Or was there a more primitive gestural communication system already in place that provided a scaffolding for the emergence of vocal language?

Rizzolatti's discovery can help us solve this age-old puzzle. He recorded from the ventral pre-motor area of the frontal lobes of monkeys and found that certain cells will fire when a monkey performs a single, highly specific action with its hand: pulling, pushing, tugging, grasping, picking up and putting a peanut in the mouth etc. Different neurons fire in response to different actions. One might be tempted to think that these are motor "command" neurons, making muscles do certain things; however, the astonishing truth is that any given mirror neuron will

also fire when the monkey in question observes another monkey (or even the experimenter) performing the same action, e.g. Tasting a peanut! With knowledge of these neurons, you have the basis for understanding a host of very enigmatic aspects of the human mind: "mind reading" empathy, imitation learning, and even the evolution of language. Anytime you watch someone else doing something (or even starting to do something), the corresponding mirror neuron might fire in your brain, thereby allowing you to "read" and understand another's intentions, and thus to develop a sophisticated "theory of other minds." (I suggest, also, that a loss of these mirror neurons may explain autism — a cruel disease that afflicts children. Without these neurons the child can no longer understand or empathise with other people emotionally and therefore completely withdraws from the world socially.)

(Another important piece of the puzzle is Rizzolatti's observation that the ventral pre-motor area may be a homologue of the "Broca's area" — a brain centre associated with the expressive and syntactic aspects of language in humans).

These arguments do not in any way negate the idea that there are specialised brain areas for language in humans. We are dealing, here, with the question of how such areas may have evolved, not whether they exist or not.

Mirror neurons were discovered in monkeys but how do we know they exist in the human brain? To find out we studied patients with a strange disorder called anosognosia. Most patients with a right hemisphere stroke have complete paralysis of the left side of their body and will complain about it, as expected. But about 5% of them will vehemently deny their paralysis even though they are mentally otherwise lucid and intelligent. This is the so-called "denial" syndrome or anosognosia. To our amazement, we found that some of these patients not only denied their own paralysis, but also denied the paralysis of another patient whose inability to move his arm was clearly visible to them and to others. Denying ones own paralysis is odd enough but why would a patient deny another patient's paralysis? We suggest that this bizarre observation is best understood in terms of damage to Rizzolatti's mirror neurons. It's as if anytime you want to make a judgement about someone else's movements you have to run a VR (virtual reality) simulation of the corresponding movements in your own brain and without mirror neurons you cannot do this.

The second piece of evidence comes from studying brain waves (EEG) in humans. When people move their hands a brain wave called the mu wave gets blocked and disappears completely. Eric Altschuller, Jamie Pineda, and I suggested at the society for neurosciences in 1998 that this suppression was caused by Rizzolati's mirror neuron system. Consistent with this theory we found that such suppression also occurs when a person watches someone else moving his hand but not if he watches a similar movement by an inanimate object. (We predict that children with autism should show suppression if they move their own hands but not if they watch some one else. Our lab now has preliminary hints from one highly functioning autistic child that this

might be true (social neuroscience abstracts 2000).

The big bang of human evolution

The hominid brain grew at an accelerating pace until it reached its present size of 1500 cc about 200,000 years ago. Yet uniquely human abilities such the invention of highly sophisticated "standardised" multi-part tools, tailored clothes, art, religious belief and perhaps even language are thought to have emerged quite rapidly around 40,000 years ago — a sudden explosion of human mental abilities and culture that is sometimes called the "big bang." If the brain reached its full human potential — or at least size — 200,000 years ago why did it remain idle for 150,000 years? Most scholars are convinced that the big bang occurred because of some unknown genetic change in brain structure. For instance, the archaeologist Steve Mithen has just written a book in which he claims that before the big bang there were three different brain modules in the human brain that were specialised for "social or Machiavellian intelligence," for "mechanical intelligence" or tool use, and for "natural history" (a propensity to classify). These three modules remained isolated from each other but around 50,000 years ago some genetic change in the brain suddenly allowed them to communicate with each other, resulting in the enormous flexibility and versatility of human consciousness.

I disagree with Mithen's ingenious suggestion and offer a very different solution to the problem. (This is not incompatible with Mithen's view but it's a different idea). I suggest that the so-called big bang occurred because certain critical environmental triggers acted on a brain that had already become big for some other reason and was therefore "pre-adapted" for those cultural innovations that make us uniquely human. (One of the key pre adaptations being mirror neurons.) Inventions like tool use; art, math and even aspects of language may have been invented "accidentally" in one place and then spread very quickly given the human brain's amazing capacity for imitation learning and mind reading using mirror neurons. Perhaps any major "innovation" happens because of a fortuitous coincidence of environmental circumstances — usually at a single place and time. But given our species' remarkable propensity for miming, such an invention would tend to spread very quickly through the population — once it emerged.

Mirror neurons obviously cannot be the only answer to all these riddles of evolution. After all rhesus monkeys and apes have them, yet they lack the cultural sophistication of humans (although it has recently been shown that chimps at least do have the rudiments of culture, even in the wild). I would argue, though, that mirror neurons are necessary but not sufficient: their emergence and further development in hominids was a decisive step. The reason is that once you have a certain minimum amount of "imitation learning" and "culture" in place, this culture can, in turn, exert the selection pressure for developing those additional mental traits that make us human. And once this starts happening you have set in motion the autocatalytic process that culminated in modern human consciousness.

A second problem with my suggestion is that it doesn't explain why the many human inno-

vations that constitute the big bang occurred during a relatively short period. If it were simply a matter of chance discoveries spreading rapidly, why would all of them have occurred at the same time? There are three answers to this objection. First, the evidence that it all took place at the same time is tenuous. The invention of music, shelters, hafted tools, tailored clothing, writing, speech, etc., may have been spread out between 100k and 5k and the so-called great leap may be a sampling artefact of archaeological excavation. Second, any given innovation (e.g. speech or writing or tools) may have served as a catalyst for the others and may have therefore accelerated the pace of culture as a whole. And third, there may indeed have been a genetic change, but it may not have been an increase in the ability to innovate (nor a breakdown of barriers between modules as suggested by Mithen) but an increase in the sophistication of the mirror neuron system and therefore in "learnability." The resulting increase in ability to imitate and learn (and teach) would then explain the explosion of cultural change that we call the "great leap forward" or the "big bang" in human evolution. This argument implies that the whole "nature-nurture debate" is largely meaningless as far as humans are concerned. Without the genetically specified learnability that characterises the human brain Homo sapiens wouldn't deserve the title "sapiens" (wise) but without being immersed in a culture that can take advantage of this learnability, the title would be equally inappropriate. In this sense human culture and human brain have co-evolved into obligatory mutual parasites — without either the result would not be a human being. (No more than you can have a cell without its parasitic mitochondria).

The second big bang

My suggestion that these neurons provided the initial impetus for "runaway" brain/ culture co-evolution in humans isn't quite as bizarre as it sounds. Imagine a Martian anthropologist was studying human evolution a million years from now. He would be puzzled (like Wallace was) by the relatively sudden emergence of certain mental traits like sophisticated tool use, use of fire, art and "culture" and would try to correlate them (as many anthropologists now do) with purported changes in brain size and anatomy caused by mutations. But unlike them he would also be puzzled by the enormous upheavals and changes that occurred after (say) 19th century — what we call the scientific/industrial revolution. This revolution is, in many ways, much more dramatic (e.g. The sudden emergence of nuclear power, automobiles, air travel, and space travel) than the "great leap forward" that happened 40,000 years ago!

He might be tempted to argue that there must have been a genetic change and corresponding change in brain anatomy and behaviour to account for this second leap forward. (Just as many anthropologists today seek a genetic explanation for the first one.) Yet we know that present one occurred exclusively because of fortuitous environmental circumstances, because Galileo invented the "experimental method," that, together with royal patronage and the invention of the printing press, kicked off the scientific revolution. His experiments and the earlier invention of a sophisticated new language called mathematics in India in the first millennium AD (based on place value notation, zero and the decimal system), set the stage for Newtonian mechanics and

the calculus and "the rest is history" as we say.

Now the thing to bear in mind is that none of this need have happened. It certainly did not happen because of a genetic change in the human brains during the renaissance. It happened at least partly because of imitation learning and rapid "cultural" transmission of knowledge. (Indeed one could almost argue that there was a greater behavioural/cognitive difference between pre-18th century and post 20th century humans than between Homo erectus and archaic Homo sapiens. Unless he knew better our Martian ethnologist may conclude that there was a bigger genetic difference between the first two groups than the latter two species!)

Based on this analogy, I suggest, further, that even the first great leap forward was made possible largely by imitation and emulation. Wallace's question was perfectly sensible; it is very puzzling how a set of extraordinary abilities seemed to emerge "out of the blue." But his solution was wrong. The apparently sudden emergence of things like art or sophisticated tools was not because of god or "divine intervention." I would argue instead that just as a single invention (or two) by Galileo and Gutenberg quickly spread and transformed the surface of the globe (although there was no preceding genetic change), inventions like fire, tailored clothes, "symmetrical tools," and art, etc. may have fortuitously emerged in a single place and then spread very quickly. Such inventions may have been made by earlier hominids, too (even chimps and orangs are remarkably inventive — who knows how inventive Homo erectus or Neanderthals were?). But early hominids simply may not have had an advanced enough mirror neuron system to allow a rapid transmission and dissemination of ideas. So the ideas quickly drop out of the "meme pool." This system of cells, once it became sophisticated enough to be harnessed for "training" in tool use and for reading other hominids minds, may have played the same pivotal role in the emergence of human consciousness (and replacement of Neanderthals by Homo sapiens) as the asteroid impact did in the triumph of mammals over reptiles.

So it makes no more sense to ask "why did sophisticated tool use and art emerge only 40,000 years ago even though the brain had all the required latent ability 100,000 years earlier?" — than to ask "why did space travel occur only a few decades ago, even though our brains were pre-adapted for space travel at least as far back Cro magnons?" The question ignores the important role of contingency or plain old luck in human evolutionary history.

Thus I regard Rizzolati's discovery — and my purely speculative conjectures on their key role in our evolution — as the most important unreported story of the last decade.

V.S. Ramachandran is Director of the Center for Brain and Cognition and Professor with the Psychology Department and Neurosciences Program at the University of California, San Diego, and Adjunct Professor of Biology at the Salk Institute. Ramachandran initially trained as a doctor and subsequently obtained a Ph.D. from Trinity College at the University of

Cambridge. Ramachandran's early work was on visual perception but he is best known for his experiments in behavioral neurology, which, despite their apparent simplicity, have had a pro - found impact on the way we think about the brain. He has been called "The Marco Polo of neu - roscience" by Richard Dawkins and "The modern Paul Broca" by Eric Kandel.

In 2005 he was awarded the Henry Dale Medal and elected to an honorary life fellowship by the Royal Instituion of Great Britain. His other honours and awards include fellowships from All Souls College, Oxford, and from Stanford University; the Presidential Lecture Award from the American Academy of Neurology, two honorary doctorates, the annual Ramon Y Cajal award from the International Neuropsychiatry Society, and the Ariens-Kappers medal from the Royal Netherlands Academy of Sciences. In 2003 he gave the annual BBC Reith lectures and was the first physician/psychologist to give the lectures since they were begun by Bertrand Russel in 1949. In 1995 he gave the Decade of the Brain lecture at the 25th annual (Silver Jubilee) meeting of the Society for Neuroscience. Most recently the President of India conferred on him the second highest civilian award and honorific title in India, the Padma Bhushan.

Ramachandran has published over 180 papers in scientific journals (including five invited review articles in the Scientific American). He is author of the acclaimed book "Phantoms in the Brain" that has been translated into nine languages and formed the basis for a two part series on Channel Four TV (UK) and a 1 hour PBS special in USA. NEWSWEEK magazine has named him a member of "The Century Club" – one of the "hundred most prominent people to watch in the next century."

In humans, mirror neurons are found in the inferior frontal cortex, close to Broca's area, a language region. This has lead to suggestions that human language evolved from a gesture performance / understanding system implemented in mirror neurons. Mirror neurons certainly have the potential to provide a mechanism for action understanding, imitation learning, and the simulation of other people's behaviour.[11] However, like many theories of language evolution, there is little direct evidence either way. Footnotes Edit. â† V.S. Ramachandran, MIRROR NEURONS and imitation learning as the driving