The Science Studio
With V.S. Ramachandran

ROGER BINGHAM: V.S. Ramachandran is director for the Center for Brain and Cognition at the University of California San Diego and an adjunct professor at the Salk Institute. He was originally trained as a doctor and over the years he has pursued two parallel careers, one in human vision and the other in behavioral neurology. He was awarded the prestigious Henry Dale medal and was elected to an honorary life fellowship by the Royal Institution of Great Britain in 2005. He was also elected to a fellowship at All Souls College. And in 2003, he gave the wreath lectures on the British Broadcasting Corporation, the BBC. Which later became a book, called *A Brief Tour of Human Consciousness*. He is a world renowned brain researcher widely known for the ingenuity and elegance of his experiments and the oxford biologist Richard Dawkins, who wrote *The Selfish Gene*, once called Rama the Marco Polo of neuroscience, so welcome.

One thing to begin with, could you explain the V.S?

V.S. RAMACHANDRAN: It's Vilyanur Subramanian.

BINGHAM: And your parents' dedications are Vilyanur Subramanian and Vilyanur Meenakshi. So is Vilyanur a family name? How does it work?

RAMACHANDRAN: Vilyanur is a family name, but we do have this curious custom in southern India, where we flip it around. And Ramachandran is in fact, my given name. I don't know how it happens, V. S. Ramachandran and my father is V. M. Subramanian. I understand this happens in other countries, for example, in China.

BINGHAM: You've also written about the important contribution of India, in terms of mathematicians and scientists, and so on. Before we get into your own career, could you just give us some sort of sense of the background of this, the…

RAMACHANDRAN: Sure, At the risk of sounding a bit jingoistic, what I would say is that people throughout the world, even Indians, settled abroad. When you think of India you think of curry, and you think of cows, holy cows and you sometimes think of yoga, which is a positive thing, or meditation, things of that nature. What people overlook is the fact that a great deal of science originally comes from India. For example, geometry is mainly Greek, so we don't deserve the credit for that. On the other hand, a great deal of arithmetic and number theory comes from India. For example, as everybody knows, the idea of zero, comes from India, not just the symbol zero, this is a mistake commonly made by people who don't know. Not just the symbol, but the notion of zero as a place marker and the use of what we call the positional coding in the number system. So if you have 453, it is 4 multiplied by 100, 5 multiplied by 10, and 3 by 1.

So at a time, a Roman soldier, you asked him…or a Roman king, if you asked him to multiply 25 by 22, it would take an entire wall and about half an hour. The average Indian peasant could do it in about 10 seconds using the number system. This then spread from India to the Caliph of Baghdad around the 7th or 8th century AD. From there it went to Europe. It is not just…it is place value, plus zero, plus the actual numbers which we call Arabic numbers, but in fact came from India. 1,2,3,4, the symbols. You need the combined, the combination of zero and place values and the actual compact system of ten numbers, to get mathematics off the ground. Then it went via the Arabs, to the moors, via the moors, to Spain, where the monks and the clergy kept it going. Initially there was great reluctance to accept it. That's where the word cipher comes from. Cipher in Indian means zero, in Arabic means zero. But Cipher also means a mysterious code. So they regarded this as an example of oriental treachery, using magic to conceal some information. But eventually, after another 300 years, Fibonacci came along and accepted this, and then it spread throughout Europe, and hence modern mathematics, and hence computers.

I don't want to go on like this, there are many discoveries that did originate in India. But one thing that did not originate in India, and I mention that, is the idea of proof. They thought they are too smart, and you don't need to prove things. That is a uniquely Greek notion, and in fact, not even Greek. Even the Greeks thought they were too clever for proof. If you remember, Aristotle, made pronouncements, and decided you don't need to prove them. And so heavy objects of course fall faster. Its common sense, it doesn't need proof. And the idea of proof comes from one man, and Italian guy named Galileo. It's amazing if you think about it, okay, thousands of years anybody could have gone on top of a big tower and taken a cannonball and a pea and dropped it. It takes ten seconds to check his idea right? Nobody did. It took 3000 years and then Galileo comes along and actually does the experiment, that's all he does. Sure enough they fall at the same time, hit the ground at the same time, so the idea that you can actually ask questions about nature, do experiments, so it's not so much the idea of proof, but the idea of experiments, comes from Galileo. The Greeks did have an idea of proof, for example proving geometric theorems, but the idea of experiments, is alien to the human mind, its now commonplace we all do it. We now know about controlled experiments, and so on and so forth. The basic idea of experiments is alien to common sense and alien to the human mind.

BINGHAM: And it got Galileo into a lot of trouble?

RAMACHANDRAN: It got Galileo into a lot of trouble, initially. Exactly.

BINGHAM: So, were you born in India?

RAMACHANDRAN: Yes, I was born in India, but to some extent I was raised all over the world, especially in Thailand and Bangkok. My father was a diplomat there, so he shuttled me back and forth between Bangkok and Madras. I was very mixed up.

BINGHAM: But your family, I remember when we first met, we talked about this, didn't your grandfather or great grandfather write the constitution of India?

RAMACHANDRAN: My grandfather, on the maternal side, Alladi Krishnaswamy Iyer, he in fact wrote the constitution of India, along with Ambedkar, so he is the co-architect of the constitution of India.

BINGHAM: So there is some sort of political and legal background in the family as well?

RAMACHANDRAN: Yes, but most of my family is in fact scientific, academic, medical. He was an anomaly, in a sense. But yes, you know, scholarly. Either law, or the professions, or science.

BINGHAM: And your parents?

RAMACHANDRAN: My father was an engineer

BINGHAM: Are they still alive by the way?

RAMACHANDRAN: No, my father died nearly 25 years ago, my mother is still alive. And, he was the head of industry in the United Nations, peak of fame in Thailand. That's why I said diplomatic service. I've been to Singapore, Thailand, Indiana, back and forth. So I was very muddled because I would spend six months in school in England, and six months in India. And the syllabus didn't overlap that much, so, it was disorienting, but

BINGHAM: This is why you are fluent when you order food in a Thai restaurant? I now understand. Did your parents interest you in science, or was it something that emerged from the uncles or?

RAMACHANDRAN: It emerged from the interaction, and from my uncles, and my mother, actually, got me excited about science. My father was a pragmatic man, he said get into medicine because then you are assured of a living and because you can be a no-good doctor and get away with it. But you can't be a no-good scientist and get away with it. So he said, get into medicine, and later if you are mainly interested in science, you can always shift gears and get into science.

BINGHAM: **S**o, I remember getting a chemistry set when I was growing up, did you?

RAMACHANDRAN: Yeah, I was passionate about science from a very early age, from maybe 10 or 11 and I had very good science teachers in Bangkok. And that makes a huge difference. They would give us chemicals, and they would tell us about experiments, and give us chemicals and say, go try this at home. This would be unheard of today because they are worried about legal consequences.

BINGHAM: This is Mrs. Vanit and Mrs. Panachura.

RAMACHANDRAN: You've got a great memory, yes, Mrs. Vanit and Mrs. Panachura.

BINGHAM: But they let you take the chemicals home?

RAMACHANDRAN: Yes, they let us take them home. I remember Mrs. Panachura taking a piece of magnesium ribbon, and lighting it, so it was burning and then it's burning and its getting oxidized. And then she would dip it into water, and it would continue burning in the water, magic. The great thing, you start with magic, and then you tell people, no it's not magic. There's a clear explanation for it. The magnesium is actually extracting the oxygen from the water. I think that's what all of science is about.

This is equally true in my next phase when I got into visual illusions. Illusions are like magic, they violate common sense, how can this line seem longer than this line? When I put a ruler and find that they are exactly the same length. Knowing this doesn't help, and there are dozens of visual illusions where you see these, and however much you know its an illusion, it doesn't help. Illusions are anomalies. They violate common sense. But then you try to explain it. The process of trying to explain it, and finally you say, "Aha, I've got the explanation." That's wonderful, translating magic into science.

This is what I think most scientists do, and certainly I do, whether it's playing with chemicals or doing experiments on visual illusions, or doing experiments on neurology. Something spooky- a patient says my arm is missing, but I still feel it's there. Or a patient says, my arm doesn't exist, doctor, here is a person who is completely lucid and intelligent, with a lesion in the right parietal, says this arm doesn't belong to me, it belongs to my grandmother. How can somebody, who is completely lucid and intelligent, assert that? So there is a thread going through all of this, that's what I'm trying to say, from my childhood chemistry experiments all the way to neurology.

BINGHAM: When I first met you, you were actually working on… the things that we talked about at length in those days, was your visual illusions, the visual system, and also the phantom limb work. I think the reputation you had then, although obviously there's now this enormous body of work, so that people listen to what you've been saying. And say that, perhaps if Rama's done it, there's something intriguing going on there, there was a joke of saying Rama has an N of 1. In other words, in science, he has one example, only a number of 1, whereas most science is conducted by people who have vast databases, draw graphs and so on. Obviously there is a problem of trying to convince people

RAMACHANDRAN: Credibility.

BINGHAM: Credibility.

RAMACHANDRAN: Well, the answer to that, is when you have a track record, people believe you more, a, and b, I mean the short answer is, you start with an N of 1, and then you have to confirm it, you have to do lots of experiments, but I like to be the one who does the N of 1, and then of course you have to dot the I's, cross the T's, do more experiments. But let me give you a couple of analogies. One of my favorite analogies is if I bring a pig into this room right now, and I say this pig can talk, and you say really, what do you mean, the pig can talk? And I wave my wand and all of a sudden the pig starts talking. What would be your reaction? You would say, My God! You wouldn't just say that's an N of 1. Show me another pig. And yet, this used to be the reaction of many scientists.

And forget about pigs, look at the history of science. Even look at hard science, like physics. We just talked about Galileo, his two most famous experiments were taking a pea and a cannonball and dropping them. That was an N of 1, initially. The second experiment was when he looked through a telescope. People think that Galileo invented the telescope, he didn't. It was used by children as a toy, invented somewhere in Italy, and he's walking around the street and he saw this thing, it's a cardboard thing with two lenses. And people are mainly using it to look at other people, to spy on other people. And he says, My God, why don't I get this and look at the heavens? And all he did was tilt it 45 degrees and look at the heavens instead of looking at people. I'm simplifying it, he of course polished the lenses to eliminate chromatic aberrations and all that, but once you have done that, You look at the milky way, my god! it's thousands and thousands of stars. Then he looks at Jupiter, and he says, my god, here is Jupiter, and there are three dots near that, what are they? Nobody has ever seen this before.

BINGHAM: Imperfections?

RAMACHANDRAN: No in fact, so he kept looking, and one of them disappeared, both of them have disappeared, and he said my god, the dots have disappeared.

Waited a little bit, and the dots reappeared. He said, I know what it is, it's moons going around Jupiter. That's why they are temporarily occluded. So he said my god, if things can go around Jupiter, then maybe not everything goes around the earth. So in that N of 1, that one little observation, he dethroned the geocentric view of the universe and replaced it with the heliocentric.

There's more to it – he looked at Venus and saw that it went through phases like the moon, but the point is, these very simple observations, just using a cardboard tube, that's the birth of physics. Or Roentgen looking at x-rays - you have a cathode ray tube, switches it on, has x-ray film, or not x-ray, regular film, and finds that the film is in the drawer, but it's blackened. He thinks my god, something must be going through. Then he put his wife's hand there – wife's hand, not his own hand – and he finds that he sees the bones there in the x-ray film, this is an N of 1. He knew nobody would believe him, he put it in the newspaper because he didn't want to go through the refereeing system. He put it in the newspapers, the next day his wife's hand, including the wedding ring, is all over the newspapers in Europe. The rest is history- he got the Nobel Prize. And I can go on and on like that.

In neurology, in my own field, every major discovery, whether it's Broca's aphasia, Wernicke's aphasia, the language disturbances that occur when language areas are damaged, neglect – where you neglect the entire left side of the visual field when the right hemisphere is damaged, and also agnosia? Denial of paralysis, blindsight – where the person has damage to the visual cortex, is completely blind and can reach out and touch objects in the region where he is blind and can't see anything – all of these discoveries: commisurotomy, split brain patients, were based on an N of 1 or N of 2, initially. And in fact, I'll go a step further, not a single discovery has been made by saying let's analyze all the data from hundreds of patients and see if there is a trend. I'm not saying that never happens, but there is a lesson here. Why is it 30 discoveries have been made with an N of 1 and not a single one by averaging? I'm overstating it a bit, but I think that's roughly true. So the short answer is you have to start somewhere and then obviously you need to confirm it. And if you have a good track record, then people believe you.

BINGHAM: Why don't you go into a little bit more detail about one those things about how you turn an N of 1…For example I remember turning up and seeing you with a patient with a patient whose name I think was Derek if I'm thinking correctly, who had had a motorcycle accident. He was missing an arm, but when you touched certain parts of his face with a q-tip, he had what he reported a sensations in his hand and his arm.

RAMACHANDRAN: That's a good example and we're interested in phantom limbs. I've always been interested in that, I haven't met anyone who's not interested in phantom limbs. I started when I was a medical student, I'd see patients who were missing an arm, and who would say, I can still feel it reaching out to grab objects, or waving goodbye or shaking your hand. I mean the guy wasn't stupid or deluded, he knew there was no arm, it's not a hallucination, but he had a very compelling feeling that the arm was still there. And the question is how do you go about studying this because this has been known for over 100 years, goes back to Silas Weir Mitchell who coined the phrase, phantom limb.

So I had a patient sitting in my office, blindfolded him and simply touched him- these were inspired in part by earlier experiments in animals, but it had never been done in a clinical context. I had this patient, Derek, who's blindfolded, his entire left arm had been amputated above the elbow about ten years earlier and I took a q-tip and touched different parts of his body and asked, what do you feel? Remember his left arm is amputated and he had a vivid left phantom arm. Well he said, oh you're touching my face on the right side, what about that? That's my forehead. What about that? That's my chest. What about that? That's my belly and it tickles. So I kept touching in different parts of the body. And then I said what about that (touches face) and he said Oh my god! That feels like you are touching my phantom thumb, my missing phantom thumb. How about that? My phantom index finger. How about that? My phantom pinkie.

And I took a felt pen and drew the individual digits on his face – the thumb, the index finger, the pinkie, and very clearly delineated regions. There was a complete remapping. And why does this happen? So I looked at the Penfield map – it simply means the entire left side of your body, the skin surface, is mapped onto the right side of your brain. There is a vertical strip called the postcentral gyrus behind the central furrow in the brain and this vertical strip has a complete map of the entire left side of the body in your right hemisphere. By map I mean every point on the skin's surface has a corresponding point on the surface of the brain. The map is systematic in fact it's like a person draped on the surface of the cortex, you may have seen pictures of this. The amazing thing is it is a continuous map, which is what you mean by a map, it's topography. But some parts are dislocated, so the hand region of the map is actually right next to the face region, it is not clear why. In other words, the head instead of being near the neck where it should be, is dislocated and it's below the hand.

That gave me the clue and I said my god what's going on here is you've amputated the arm so the sensory region corresponding to the hand in the brain is deprived of sensory input – is hungry for sensory input, maybe secretes a chemical, a neurotrophic factor, and then the fibers that are going from the adjacent face skin to the face region of the cortex invade the vacated territory corresponding to the missing hand, so when you touch the face that message goes not only to the face area like it should, but invades the territory corresponding to the missing hand, activates the hand area of the brain, so the brain is fooled into thinking you are touching the missing hand.

So here is an example of how you can play Sherlock Holmes with these patients. You start with a very – with magic. Why would somebody in their right mind say that when you touch his face you are touching his fingertips? Why would you get a systematic map? Now, it's an N of 1, but it was almost too good to be true you say. Well look it fits with what we know about the anatomy. I had him come back three weeks later, of course he had cleaned his face, there was nothing there. And I remapped it, and you get the same map. And you map with a felt pen and you take a photograph, perfect registration. How could he have memorized this? Unless every day when he went home he did it again, looked in the mirror, it was all very far fetched. So I knew this was real at once. But of course, I sent the paper to *Science* and it was published, fortunately, even though there's an N of 1, but then we repeated this on dozens of patients. Sure enough there's some variability, but other groups have repeated it since then, so you have an intuition of when an N of 1 is valid and when it's not valid.

BINGHAM: Has it gone beyond that to where the neuroscience part of it has been proven out?

RAMACHANDRAN: Yes. So this is an example of a black box approach. You do something, external to the system so to speak, then you ask the subject what he's experienced. Then you come up with a model based on what's known about the brain, preferably constrained by the neuroanatomy. You can come up with a black box model without even knowing anything about the brain, but if you know something about the brain then that reduces the problem space and makes it easier to do. So we came up with this theory about what's going on. Then we had a couple of patients, we did MEG, magneto encephalography, which is a brain imaging technique which allows you to fairly precisely, localize – if I touch the finger for example, the index finger and the ring finger, different points on the map are excited. So I can map the surface of the skin on the brain without opening the skull. And we did that on these patients. In a normal person, if you touch the hand it goes to the hand area, if you touch the face it goes to the face area. In these patients, if you just touch the face, it goes not only to the face area but has invaded the hand area that also lights up. This has been published in *Nature*, experiments done with Floyd Bloom and Tony Yang who was a medical student working in our lab at that time. So there's a perfect fit for the perception on one hand, perception anomaly, change in perception, and change in the brain map. This is one of the goals of cognitive neuroscience, trying to link phenomenology, psychology, with neuroanatomy and neural connections. And one important thing it showed was at that time, nearly 15 years ago, the dogma was that connections – this is what I was raised with as a medical student and generations of students in psychology, undergraduates, are raised with this Penfield map – and it is assumed this is laid down at birth and all connections in the brain are laid down in the fetus or in early infancy and you can't change these connections in the adult brain, by and large. And that's why it is so difficult to treat neurological disorders, when it is damaged, that's it. So we had challenged that dogma, and said look, in the adult human brain, here is a change of a basic map, the Penfield map which every student learns about, over a distance of a centimeter or more, in a matter of couple of weeks and in fact later we showed, in a matter of a couple of days, this map changes. Although to get the one centimeter change, it does take a few weeks. So this shows, new connections can emerge in the adult brain and since then there have been a number of studies showing it, but I believe that was the first demonstration of large-scale changes in topography in the adult human brain.

BINGHAM: I think one of the most important topics at the moment in neuroscience, is the concept of plasticity. Until fairly recently, it was thought that you are born with a certain complement of neurons, nerve cells, and it was all downhill from here, because they just die off and we now know that that's not the case.

RAMACHANDRAN: Absolutely. And the dogma at that time was that connections cannot be changed, but in our own campus here, Rusty Gage and Terry Sejnowski, and the work they've done shows tremendous malleability of connections in the adult human brain. Here in neuron valley, a lot of the discoveries were made.

BINGHAM: You've said somewhere that you need to be obsessively, passionately, almost pathologically, curious. Science is a love affair with nature. Is that..?

RAMACHANDRAN: Yeah, I think I still believe in that. I think that in many ways it is like a love affair, with its ups and downs, and the obsession and the passion, but let me qualify that. You have to be obsessive, you have to be passionate, but you have to be playful and detached. This sounds like an oxymoron, how can we get obsessed and yet be playful? But I think this characterizes – I'm not talking about me – but many great scientists like Francis Crick, was a colleague of ours here not long ago, you watch him at work and proof of the pudding, he discovered DNA, the structure of DNA of the genetic code. He is obsessive, he is passionate, he is having a love affair, but at the same time there is this playful sense of whimsical, playfulness to the whole enterprise and I think that combination is very potent. You don't want to get too obsessive and too caught up in it. And it may not work for everybody by the way there are different styles of doing science. It certainly, is something I enjoy and it's what I do.

BINGHAM: Otherwise, as you said, if you do that too much you become as you put it in one place, neurotic. You had two incompatible ideas in your household, one that you were the chosen one, the very best. And that secondly, that you were never good enough for your parents. That seems to be a rather daunting environment to grow up in.

RAMACHANDRAN: I know, and I think it's true of many groups of people. I had a Jewish post-doc in my lab, Eric Altschuler who is brilliant and now doing residency in New York, and he told me that part of that whole culture, and it may be true of American culture in general, but certainly true of his home and part of his culture, is that the parents implant in you, and this is true in India of certain groups, that parents implant in you two incompatible ideas. On the one hand, you're perfect! You are the chosen one. On the other hand, you are never good enough for me. So, if Eric or I were to call our mothers, and say I just got the Nobel prize. Your mother's not going to say, hey, congratulations, that's wonderful. I know what my mother would say, she would say, I hope you didn't share it with anybody. This is a recipe for neurosis. You become totally… what do you do? But it's a great recipe for making you successful, obsessed, all of those things.

BINGHAM: There's a curious, I was also reading about some of your childhood heroes, why don't you in fact say, some of the major forces on you as you were growing up, some of the major influences.

RAMACHANDRAN: Well there's two answers to that. One answer is of course your parents, have a major influence on you. But in terms of teachers, I think the most contagious thing in the world is passion. Now somebody has to be very knowledgeable obviously, but that's not enough. I have sometimes, the other day I was strolling in Golden Gate Park in San Francisco, and somebody was giving a talk at the museum of art there, on Kashmiri shawls, which I have never heard of and I don't know anything about except that some people buy them and then use them, right? So I said, why would I want to go to a talk on Kashmiri shawls? And I go there, and I was absolutely riveted. There's a chap who collects Kashmiri shawls, and he was talking about it, and I said I'm going to leave in ten minutes, and I couldn't help sitting there listening for an hour and a half, listening to this chap, he was so passionate about it – gave us the whole history of it, how the British came and employed child labor, and all sorts of things, and the beauty and elegance, the connoisseurship of Kashmiri shawls, and I went home, I went to India, I said I have to buy a few of these. I think that passion is contagious, and I wish that more of our school teachers would be like that, and it reminds me of Dead Poet's Society. A classic example would be Robin Williams – the role played by Robin Williams in that movie – and so I had very good, I was very fortunate in having teachers who were very passionate.

But in terms of scientific heroes, I was always interested in the history of science, and that's another thing missing from our curricula, because I think you can learn a lot from the history of science, and I was always enchanted by Victorian science, by Thomas Henry Huxley, Michael Faraday – one of my heroes. Speaking of N of 1, here's a man who takes a magnet, he was a book binder, never had any formal education, he takes a magnet, moves it to and fro in a coil and says my god, there's a current produced. If I just put a galvanometer, there's a current. And he links two areas of science which until then had been completely separate. Magnetism on one hand, and electricity on the other hand. It was the birth of electromagnetic induction, which is the basis of all motors we use today – practical importance. But also theoretically, it paved the way for Maxwell's field equations, people forget that. So you have the N of 1 experiment, that in turn sets the stage for the theoretical views of Maxwell. So he has always been one of my heroes, because he does very simple experiments.

Or take another one. People are talking about magnetic fields, and everybody said well how do you know there are such fields, maybe like ether, it doesn't exist. So he takes a bar magnet, puts it behind a sheet of paper, he sprinkles iron filings on it! Can you think of anything more simple than that? Lo and behold, you see the fields. It's not some concept. Immediately you see these fields. Nobody can argue with that. N of 1. For the first time anybody had experimentally, of course I'm simplifying it here, but it was an experimental demonstration of the magnetic field.

BINGHAM: Two points there. One- there was a time, Faraday was a demonstrator at the Royal Institution of which you just became a lifetime fellow with Humphrey Davy. And demonstrated, performed the Christmas lectures for children, which still go on to this day. So there was a tradition, in the Victorian times of actually communicating science because it was important to do that. I think to some extent, I'd be interested to know from you whether you think that's been lost. And secondly, the history of science – knowing the background of a subject and so on. Perhaps that's difficult, what do you think, when if you're looking at last year's text book, you're out of date. It's very tricky to keep up with the whole business of science.

RAMACHANDRAN: It's all the more important that you have to look at the history of science to keep your sense of perspective. Last year's textbook is out of date, you have to go to conferences, you have to attend meetings, you have to go to posters, often you learn a great deal but I find myself learning much more from talking to people, rather than actually going to the posters. If you pardon my saying so, you go to Society for Neurosciences, there are 20000 posters. First, you can't take all of it in. Secondly, you get this weird feeling that people have taken all the abstracts from the previous year, taken all the key words, and jumbled them up in a random order in the computer, and then you get all of this years abstracts. This takes a lot of the joy and romance out of science. So I often tell students, go there but mainly talk to people. Go look at all the posters but then see what direction people are headed, and then go the opposite direction. I'm overstating it, but not a bad strategy.

BINGHAM: An automatic abstract generator

RAMACHANDRAN: Exactly. The other thing is that, speaking of popularizing science, in Victorian times as you said, there is a great tradition of this. All the most eminent scientists, Faraday was a great lecturer, Humphrey Davey was an even more outstanding lecturer. He discovered about 7 or 8 of the known elements at the Royal Institution. By the way, I just learned that the test tube was invented at the Royal Institution, interesting factoid.

BINGHAM: For what?

RAMACHANDRAN: The test tube.

BINGHAM: In what circumstances?

RAMACHANDRAN: To do chemical experiments.

BINGHAM: What were they using before that is what I'm trying to ask.

RAMACHANDRAN: Before that, I don't know. Terry, do you know? Beakers.

Well anyway, test tube the ultimate icon of science. Now Faraday, Thomas Huxley, all of the… Darwin of course wrote a book, John Murray was key in that it must be intelligible to anyone, not just a specialist. So popular books were being written all the time, and Huxley used to lecture to the common people, or to the working men, to use a politically incorrect, or out-of-date phrase, and he would be lecturing to coal miners about evolution, about natural selection, all of that. There is a great tradition of this, all the scientists were doing this. For some reason it became not so fashionable to do in the first 50 years of the 20th century. Maybe 1st 60 or 70 years, until people like Carl Sagan and Bronowski, and even then it was slightly frowned upon, I don't know quite why, given the great tradition of popularization in the 19th century. But I think that it's being revived thanks to people like you and John Brockman, and you know the last 15 years you go into any bookstore, Barnes and Noble, in the table there, which used to be mainly Oprah Winfrey and this and that, you see dozens of popular science books, it's overwhelming. You just go and pick up…and extremely well written and not just the ones by eminent professional scientists, also ones by science writers. Matt Ridley's book for example, on Francis Crick- just one that came to mind, but dozens and dozens of books which you wouldn't have seen 15 years ago. Not to mention popular TV program, brains are the flavor of the year. You've got a dozen programs on the brain.

BINGHAM: How do you pick a problem?

RAMACHANDRAN: Well, people often ask me this, and I think the answer is, it depends on the…you can ask me personally how I pick problems, but in general it depends on the scientist's personality. Different people have different strategies. I have this perverse streak, which is to go after anomalies. And by anomalies I mean very odd phenomena, which have been known for a long time, but which have been brushed under the carpet. You can do this a lot in neurology, you can do it when you're studying vision. Phantom limbs are an example, they've been known for 100 years and you'll be careful because it was Thomas Kune who talked about anomalies, how sometimes there's an odd observation and if it doesn't fit the big picture of science, you brush it under the carpet. Now people think my god, scientists are narrow-minded, they brush things under the carpet, but there's a good reason for ignoring anomalies, because most of them are false alarms. Telepathy is an anomaly, I hope I am not offending anyone by saying that…

BINGHAM: I knew you were going to say that

RAMACHANDRAN: Spoon bending is an anomaly, Elvis sightings are anomalies; there are dozens of examples of anomalies. Telepathy, clairvoyance, precognition, because the reason they are anomalies is not only because they don't fit the framework, but because every attempt at verification fails. So how do you know which anomaly to pursue? X-rays were an anomaly, here's something hidden inside a desk, opaque desk but the film is getting blackened because of some mysterious ray and that was the great insight that Roentgen had. When you turn on the cathode ray tube. That was an anomaly, but he saw the significance. So how do you know which anomalies are fake and which anomalies…you can spend a lifetime pursuing fake anomalies, and which ones are genuine? There's no simple answer, you have to have a nose for anomalies, that's one simple answer. But the second answer is, if something is regarded as anomalous, like continental drift, bacterial transformation, these are examples of anomalies, simply because they don't fit the big picture, then it's wise to pursue those because your big picture may be wrong and it may completely turn your scientific world view topsy-turvy. On the other hand, if something is an anomaly because it cannot be confirmed, then the more you study it, the smaller the effect, then you're in serious trouble. And this usually means it's a false alarm, a false anomaly.

So general rule of thumb, bacterial transformation was confirmed dozens of times. Continental drift, the evidence was staring at people, the borders of the continents fit perfectly, the same fossils you see in South America, you see the same dinosaur fossils you see in Brazil, you see in south Africa – I should say, West Africa. So people said, the pundits at that time said, oh well there was a great land bridge across, from Brazil to Africa and they all migrated across and died there. This is ridiculous. People said this because they couldn't think of a mechanism of how this could possibly happen. Then of course people discovered plate tectonics, and knew there was a mechanism, and people said, oh yes there is continental drift, that explains the distribution of fossils. So, coming back to neurology and brain science, I do the same thing. Look at phenomena such as phantom limb, look at phenomena like synaesthesia, which we have been studying recently, where somebody says whenever I see five it's red, six is blue, seven is green, tones: F sharp is green, C sharp is blue, you get your senses muddled up.

BINGHAM: You have a chapter here called Purple Numbers and Sharp Cheese. Do you want to elaborate on that a little?

RAMACHANDRAN: Ok so here is an example which has been known since the time of Galton, Darwin's cousin. And he pointed out that certain people see five as red and six as blue and seven as green and since then this has been replicated dozens of times. People have said yeah, you know, we have observed this, that some people do this. You also notice it runs in families, so there must be a genetic basis to this. And Galton, as you know, was very interested in the inheritance of various mental traits. He kind of overdid it, but by and large, he had some good ideas. And, the phenomena was reported, hundreds of times, not hundreds, dozens of times, but was ignored by mainstream neuroscience and mainstream psychology, because what do you make of it? When you say five is red and six is blue? It's a classic example of an anomaly.

Now, so what we did is to simply come along and rescue this from oblivion. We said no, there is something interesting going on here, because it's been repeated too many times. First of all, we found it was common, its not one in one thousand or one in ten thousand like people claimed; its one in two hundred people. So we found two students, undergraduates at UCSD, who saw five as green and seven as blue and two as yellow and so on and so forth. So the question is how do you know they're not making it up? Maybe it's like spoon bending, maybe it's like telepathy. So we did a simple clinical experiment, which showed that these people were really seeing two as red and five as green, literally. Seeing it! And how do you show that? Well you have a computerized display with lots of fives on it and all the fives are green, and you have one two in it. And of course the two is red for these people. For you and me, you see a bunch of black squiggles, because they are all black and white. And if I say, find the two embedded among the fives. Two? There's no two here. Oh yes there's a two. And you take 15, 20 seconds, 30, 40 seconds. You show it to a synaesthete and he says Oh! I see a red two on a green background, and he sees it in a second, much more quickly than you and me. So if he's crazy, how come he is much better at it than all of us? So ok, so this shows it's an authentic sensory phenomenon because he said I see it colored, red against a background of green.

So we did a number of experiments like that, if you lower the contrast of the two, the color falls off, and in fact disappears at 10 percent. All of this suggests it is a genuine sensory phenomenon. Then when we did experiments, doing brain imaging experiments with Geoff Boynton and Ed Hubbard, and showed in fact this cross wiring in the brain, in a specific region called the fusiform gyrus, this cross activation, it turns out that the number center in the brain, to put it very crudely, area which responds to visual graphemes of numbers, is right next to the color area, V4, of the brain. Right, so what's the likelihood that these are almost touching each other, and the most common type of synaesthesia is a number-color synaesthesia? We said, this can't be a coincidence, said, there is some accidental cross-wiring. Why should that be? Well the clue comes from the fact that there it runs in families, maybe there's a gene which causes pruning between adjacent brain areas as the brain develops.

So the normal brain has excess connections everywhere. Then as you develop, as the brain develops, the excess connections are pruned away or there are inhibitory transmitters producing lateral inhibition between adjacent modules. If the gene or the genes that do that mutate, then you get a faulty gene and you don't get the cross wiring, you're going to get anomalous connections between brain regions. Maybe that's what's happened in synaesthesia and that's why there is this cross-activation. So we did brain imaging experiments in normal people if you show a number, only the number lights up. In a number-color synaesthete, you show a number and the number and the color area lights up. So far so good, then you say, so what's the big deal, why am I interested in this?

Well one of the things I found out was that synaesthesia is eight times more common among artists, poets, and novelists than among the general population. Why would this be? One possibility is they are all crazy. People have said that. But another possibility is that if the same gene is expressed more diffusely throughout the brain, then you're going to get greater opportunity to link seemingly unrelated brain regions and therefore seemingly unrelated conceptual domains. And that, in turn, is the basis of metaphor. What do artists, poets, and novelists have in common? The ability to link seemingly unrelated ideas and concepts, and if ideas and concepts are also in different parts of the brain, there is greater propensity to cross-activation, makes you more prone to metaphorical thinking, maybe makes you more prone to being artistic, and that by the way, is why I think this gene is prevalent in the population. Why do one in two hundred people have this peculiarity? This would have been eliminated through natural selection hundreds of thousands of years ago. The reason it persists, it makes certain outliers in the population, there is a hidden agenda, in other words. It makes certain outliers more prone to metaphor and analogy, making them more creative. Not because it makes some people see fives as red, that's a byproduct.

So anyway, you can go all the way from a gene, if you clone it using a large enough family. Clone it, then go to brain areas, specific regions in the brain, then you go to psychophysics, doing perceptual experiments, then you go all the way to metaphor and Shakespeare and that's a wonderful thing. It's not nearly enough to take an anomaly and then discover what's causing the anomaly. Those are the first two steps. Difficult enough, right? The next step is to show that this has important implications for other aspects of brain functions and to you and me. It's not just some quirk which you're explaining.

BINGHAM: Is there a gender difference? Is there more males than females that have synaesthesia?

RAMACHANDRAN: There is indeed; it's more common in women. So there may be a sex-link basis to it, but it's not been studied carefully.

BINGHAM: Ok, because your thesis, if your thesis was that it was being maintained and passed on because there was some sort of selection pressure for it, then presumably the theory is that poets and painters and those with an artistic bent are more attractive to mates and therefore leave more offspring.

RAMACHANDRAN: Well, that has been suggested of course, by people like Miller. That is the "come and see my etchings" theory of artistic talent. And I just don't believe that, I mean, I think the problem with Ev Psych, by the way, and I've said this before in print.

BINGHAM: By which you mean…

RAMACHANDRAN: By which I mean evolutionary psychology, by which I mean you take every conceivable trait, physical or mental propensity and say, why did this evolve, it must have something to do with the way our ancestors were walking around the savanna and all the selection pressures. Now, of course, it's partly true, that some of our mental traits are because of that. But some of it has this banal ring to it. You say, you know, men like young women because they are more fertile. Ok, maybe. But a, it involves the cultural dimensions of the mind and I think what's unique about the human brain especially is we are the cultured primate; and I'm not saying this to be politically correct, I have absolutely no interest in politics. But what I'm saying is what's unique about the human brain is the fact that we have systems of neurons including mirror neurons that enable us to assimilate culture and knowledge through imitation, through emulation, through learning, much more rapidly than any other brain of any other animal. This is what makes us uniquely human.

Ok, so that's one problem with evolutionary psychology. The other, more serious problem, I think, is you can come up with any ad hoc theory you want and it becomes very difficult to test. For example, I could say, people say, well because we were on the savanna, we like this, we like young women, you know, men. And there are dozens of examples, maybe you could think of some. But you could say, well men or women like going to the Scripps aquarium. Why? Why do we like to go to the aquarium? Well its because our Devonian ancestors were fish, up in the Devonian seas, enjoy mating with other fish, obviously, and found them attractive. And maybe there's a residue of this in the brain and that's why we enjoy going to the aquarium. Now immediately that strikes you as ludicrous and absurd. Now why is it any less ludicrous, why stop at the savanna, I mean you can go all the way back? So, somehow it doesn't ring true to me, I'm not saying that the whole enterprise of evolutionary psychology is a waste of time, there are valuable insights coming from that, but you have to be careful.

BINGHAM: That's a different and longer conversation, but let me pick up the one concept there. Mirror neurons, which you wrote a long paper about when they were first, a few years after they were discovered. Would you like to explain a little bit about mirror neurons and their importance in terms of social cognition?

RAMACHANDRAN: I, yeah I'll try to do that. First of all let me say that mirror neurons don't explain everything. And there's a mirror neuron mania right now, going around. But they are extremely interesting. And just very briefly, if you record from individual cells in the brains of primates, say monkey brains. If you go to the front of the brain, the frontal lobes and record from certain parts of the frontal lobes, you will find there are neurons which respond every time a monkey makes a skilled or semi-skilled movement, apparently "volitional" movement. So the monkey reaches out to grab a peanut, one neuron fires. And undoubtedly its part of a small network of neurons, its not that one neuron is a peanut neuron. So you have to be careful of that. But it fires mainly when the monkey reaches for a peanut. Another monkey, when the monkey pulls a lever. Sorry, another neuron will fire when the monkey pulls a lever. Another neuron will fire when the monkey pushes something. Another neuron will fire when a monkey puts something in its mouth. Ok, for different actions there are different neurons firing. And this is well known, it goes all the way back to Vernon Mountcastle and we think of them as motor command neurons.

So the motor commands are somehow being programmed by networks of neurons and you can monitor this at the level of single neurons. And this is very exciting, but what's even more exciting is that about, what five, ten years ago, Giacomo Rizzolati, Iacoboni and all those other in Parma, Italy, found that some of these neurons, almost a third of them, will fire not only when the monkey reaches for a peanut, but the neuron will also fire when it watches another monkey reach for a peanut! And this was absolutely amazing when they first discovered it because it implies that the monkey is doing some sort of computation that allows it to put itself in the other monkey's shoes, ok. Adopt the other monkey's point of view, in other words.

Now, you can think of all sorts of Hebbian association arguments to explain this, but it doesn't fully explain it. Because the neuron doesn't fire if you simply have a hand moving from its own perspective, it needs to be from the other monkey's perspective. This suggests that you have what's been called a monkey-see monkey-do neuron. In other words, a mirror neuron, and this is exciting because there's this whole area of research called theory of other minds, being able to adopt another person's point of view, and the great apes can do this to some extent but humans are especially good at this. You're able to create a virtual reality simulation of what's going on in the other monkey's brain, in your brain. And so, this is the basis of interpreting, rationally interpreting another monkey's point of view, another person's point of view. What's that person up to? Also, it may be an important imitation, so if somebody does something, this is the point I made in my article, then you have to imitate it, not some sort of blind mirroring of that, but adopt that person's point of view in imitating that action.

And this of course, is the basis, believe it or not, of culture, the dawn of culture, because if you're a polar bear, you have to spend hundreds of thousands of years evolving a fur coat through natural selection, if you suddenly migrate to the north pole or something, you're a regular bear and you go to the north pole and you want to develop a fur coat. If you're a human, and you watch your mother hunt down and skin a polar bear, it's one-trial learning and I think that's based on mirror neurons. You watch her do this, its not just mirror neurons, but in conjunction with other parts of the brain and you'll do this and then you learn it and you put on, you just kill another polar bear and put the fur coat on and skip thousands of generations. Whether its hunting, or making a knife, or making fire, one of a kind innovations spread horizontally through culture and vertically, almost through Lamarckian, of course its not really Lamarckian, but inherited through culture, very very rapidly and this marks the dawn of culture, which in turn feeds back on brain evolution so you have this culture-brain co-evolution and a rapid explosive development of culture. So that's the importance I think, of mirror neurons.

One of the things my students Eric Altschuler and Lindsey Oberman and my colleague Jaime Pineda and I have shown is that in autistic children, there is a deficiency in the mirror neuron system. We don't know this for sure but there is very compelling evidence from EEG and brain imaging studies that this is the case. And if you look at the deficits you see in autism, difficulty in adopting another person's point of view, difficulty with empathy, difficulty with imitation.

Now, lets talk about empathy for a minute. You can show this in humans- mirror neurons for pain, for example; so in the anterior cingulate you put an electrode in an awake conscious patient, this has been done at UCLA, you put an electrode in the anterior cingulate, you record from neurons there, those neurons will fire when you poke the patient with a needle. This has been known for a while and they are called pain neurons. People thought there was a hotline from the pain, skin pain, receptors to a pain center in the brain. We now know there are many layers to experiencing pain, going to the insula, cortex, parts of the limbic system, eventually going to the anterior cingulate. That's all known, pain neurons.

Now the amazing thing is, what they found was when the person watches another person being poked with a needle, the pain neuron fires almost equally as strongly. Now, I don't know if its true of all the neurons, but certainly a subset of neurons do this. Now this is absolutely amazing if you think about it, because this neuron is an empathy neuron. So empathy is no longer some abstract metaphorical social phenomenon. You're seeing it at the level of neural circuitry in the anterior cingulate, monitoring it at the level of single neurons, and you're finding an empathy neuron. It's dissolving the barrier between you and another human being. So, I like to call it a Dalai Lama neuron because it's the basis of all Eastern mysticism that this illusion that you are a separate person inspecting the world and other people are different, I should be selfish, dadadada, is all an illusion, dissolve this barrier and the world will be a better place. So I'm arguing this is not just philosophy, not just metaphor, your neurons are dissolving the barrier, already dissolving it for you.

BINGHAM: There are two or three points we want to pick up there. First of all, the whole notion of being able to walk a mile in someone else's neurons, this whole notion of empathy; is that a requirement for consciousness?

RAMACHANDRAN: That's getting into a big area, consciousness.

BINGHAM: The reason I ask that is that you have said before in conversations that you thought there was a distinct cutoff between other animals and humans, that humans were unique and that humans had what we would call qualia, which is the sensation of experiencing these things.

RAMACHANDRAN: Well actually I am alone in thinking that, pretty much. I don't know, maybe there are some other colleagues.

BINGHAM: You are an N of one.

RAMACHANDRAN: Probably N of one. The idea is that there are several questions about what is consciousness. To an anesthesiologist, or a neurologist, they're talking about coma, and there is a scale and I think that's just the power supply, its coming from the brain stem and different levels of arousal and being conscious or not conscious and that's not going to get you anywhere, looking at those systems in understanding consciousness. You know, understanding the logic of consciousness, which is what we want to understand. It's like saying you need the Krebs cycle for genetics. Obviously you do, but that's not the key to understanding genetics. It's the double helical structure of the DNA molecule. So let's forget about that. Now what are the other questions concerning consciousness? There are two important questions, related. One is what we call qualia. Christof Koch and Frances Crick have championed this view and philosophers refer to this as qualia, just means sensations you are conscious of. So I poke you with a needle, its not just that you say ow, there is also an internal subjective experience of consciously, being conscious of pain. If I poke somebody else with a needle, I can describe all the pathways, everything that's active, the cascade of chemicals, neural activity, coming to the Broca's area, and you say "ow!", but I don't experience anything and there's no reason for you to postulate that that person is internally experiencing a mental phenomenon called qualia. Skinner would say that.

BINGHAM: Wouldn't you, given what you just said about mirror neurons…

RAMACHANDRAN: Yeah I'm getting there. So what I would argue is, when I poke you with a needle- that's a very important question- when I poke myself with a needle, if I look at myself with an autocerebroscope 500 years from now, and I plot the diagram and I see all of these things are going on, but my god it leaves something out, namely the internal subjective experience. Or if you're a Martian, looking at my brain, and lets say you don't have any qualia. Well forget about Martians, lets say you're Roger Bingham and you were born colorblind, you don't have any color qualia. But you are intelligent and you learn physics and you know different wavelengths, and you know other creatures like me, like Rama, other human beings, do have the pigments in the eye, and do have color neurons firing away and you show me this diagram and say look, Rama, I know everything about color vision, all of his pathways are firing away. And I say, Roger, you're missing something, and that's the crucial subjective experience of green when my green neurons fire, but not red. Subjective experience of red when my red neurons fire, which is ineffable, I cannot communicate it to you, communicate this feeling to you. So that's the qualia problem.

The separate problem, which many people have thought of as a separate problem and I don't think it is, and that is the problem of self. The person who experiences the qualia, I can reflect on my qualia. I can say, not only do I experience qualia, but I *know* that I experience qualia and I know that *I* experience qualia. So it is the subjective experience of myself experiencing qualia. There is this peculiar solipsistic quality to it. And Crick and Koch have argued, first let's solve the qualia problem and let's get to the self problem later, and I'm saying that's impossible. With all due respect to Francis and Koch, who have made enormous strides in getting people excited about this, I'm saying there is no earlier stage called qualia and subsequent stage, self inspecting the qualia-there's no such thing. And the reason is very simple, there is no such thing as free-floating qualia. It's an oxymoron without a self experiencing it. Likewise, a self without qualia, without any sensations, memories, subjective sensations, is meaningless.

So I claim that these two co-evolved in evolution and is intimately linked to language in the Wernicke's area. So let me be more specific. For qualia to have any meaning at all; there has to be meaning. So for example, when a fruit fly sticks out its proboscis, looking at a red apple; ok so lets assume it has color vision, it probably doesn't but lets assume it looks at the red apple, its almost a reflexive, obviously its creating a representation of the apple. It has to because its neural signals, its not copying the apple. But then, after the representation, comes the tongue, or the proboscis, flicking at the apple, and then it consumes parts of the apple. This is a caricature, actually. They probably do it through smell. But let's assume, for the sake of the argument, that the visual impulse goes in and they stick out the proboscis. I claim it has no qualia. And there's no point in saying it has a raw awareness of the sensation of red or apple. It doesn't. For you, on the other hand, the apple evokes tempting eve, baking an apple pie, keeping the doctor away, eating. It's got thousands, in fact virtually infinite, or if you're Newton, hey its falling, makes you think of gravity. Maybe that's what holds the solar system in place. And the implications are potentially infinite, and this is uniquely human. And this occurs, and I think it's a set of circuits in the brain.

Another point I would disagree with is the notion that there are neurons, qualia neurons or consciousness neurons. Crick says this playfully, just to be provocative, but some people take it seriously. I don't think there is any such thing. I think that when you're doing reductionism, there is the appropriate level of reductionism and the inappropriate level. So for example, when Crick talked about the reductionist basis of genetics and heredity, Watson and Crick talked about this, it turned out they were lucky, with the DNA molecule, the double helical structure and the genetic code. If they had studied quantum mechanics, and had tried to discover the genetic code at the level of quantum mechanics, they would have failed. So similarly, to understand consciousness and qualia, I don't think you're going to understand it at the level of single neurons, you're going to understand it at the level of circuitry at the brain. But, I don't think it's the entire brain that's important. It's not the activity of the entire brain, its specific to fairly circumscribed structures. What are those structures? So that allows you to hone in on the problem, and I think you need to understand the problem of self and the problem of qualia, and they are two sides of a möbius strip, or a coin. You cannot understand one without simultaneously understanding the other.

And this is where people have been led astray, thinking the self is some complicated other problem. Let's solve qualia first, eventually we'll get to the problem of self. And I think you need to tackle them simultaneously and need to map it on with a functional logic of consciousness, self, qualia, meaning. How do neurons instantiate meaning? That's the holy grail of neuroscience and I don't think lower animals even monkeys do that to the same extent. You may see some rudiments of this in great apes. I think it required the emergence of the supramarginal gyrus, which became the angulate gyrus and the… another structure in the human brain. Sorry – scratch that, the inferior parietal lobule, which splits into angulate gyrus and supramarginal gyrus in humans. Right? So that's unique to humans. And an enormous angulate gyrus which is also unique to humans. Wernicke's area, which is unique to humans, and certain other structures acting conjointly to generate your sense of self, especially the right hemisphere being involved in body image, the sense of a self being anchored in your body, the sense of planning for the future, involving partly the anterior cingulate and the frontal lobe, and the self being able to inspect the sensory information coming in. This is dangerous territory, because when you say "inspect" it makes you think of the homonculus fallacy, a little person watching, that's not what I'm saying.

I'm saying that in some state in evolution, instead of just sensory representation, you started creating what are called meta-representation- representation of the representation, unlike the fruit fly, which allows you to manipulate symbols internally in your head. And this is intimately linked to things like meaning, and this is created in the inferior parietal lobule, in conjunction with the Wernicke's area, to some extent it also linked to the sense of agency, which is there in the anterior cingulate. And all of this acting in conjunction, there's the emergence of this dual property of qualia and self, which I think is unique to humans.

BINGHAM: One argument is that the problem stated "what is consciousness?" is somewhat analogous to the problem "what is life" as it used to be asked 100 years ago. The answer was some sort of an élan vital, we don't know exactly what it is and so on and so forth. And then as you start exploring the consciousness issue, exploring the life issue, and you figure out what proteins do and you discover DNA and so on and so forth,, nobody says anymore, "what is life?" You might say, "what is meaning?" but they don't say "what is life?" because we have a whole panoply of stories from different disciplines that knit together into an answer. Do you think that – let me just go on a little bit here – is "what is consciousness?" possibly at that stage of problem at this point? I say that because in addition to the mirror neuron story there's the work of our colleague John Allman, who has found some neurons that appear in specific areas of the brain and are also apparently diminished or damaged in autistic syndrome, where these neurons appear to be useful for social cognition, allowing you to make very quick social decisions. There's lots of areas, lots of parts of the brain that we know are beginning to be identified in terms of social cognition. Its possible in the fullness of time that these may all come together and answer that question, "what is consciousness?" so it may be a non problem.

RAMACHANDRAN: Well I have three responses to that. The first response is that we shouldn't get too preoccupied with words, as you well know. Francis once told me, Francis Crick, there was never a time…and this is a problem because philosophers often raise this, they say look, you have to get clear about the terminology. I got into this problem talking about aesthetics once. You know, neural basis of aesthetics. Some philosopher got up and said, what do you mean by aesthetics? So, what do you mean by consciousness? That's a common question. So Francis was giving a talk, and some Oxford philosopher raised his hand and before he could even get into the talk, he said you're talking about consciousness without actually defining it. Give us a precise definition of consciousness and then we can proceed further. Something along those lines. So Francis said, my dear chap there was never a time when a bunch of biologists all sat around a table and said, let's first define life before we investigate it further; let's get the definition clear first. We just went out there and found out what it was. It was a helix – it was a molecule. So we leave definitions and matters of semantic hygiene to the philosophers. Often the definitions follow as you go along. It doesn't mean you shouldn't have a rough idea of what you are talking about, obviously you must. But you can have what is called a working definition, working hypothesis in the initial stages. Okay that's one answer. Now lets get to consciousness specifically.

What is consciousness? Is there going to be, is it multiple processes? We don't ask what is life? Life, as it turns out is a DNA molecule, its Krebs cycle, its mitochondrial enzymes, all sorts of processes. So if someone said, yeah but where is life in all this biochemical activity? You say it's a meaningless question. Now that could happen with consciousness, it could be as I said, qualia and self and there are other - embodiment, I feel like I'm in this body, I don't feel like I'm in Terry's body or your body. It could be, and then there's a social self; self undoubtedly involves looking at yourself from another person's point of view. So you refer to self-consciousness, being self-conscious, and this may involve mirror neurons. So self as a social construct, the unity of self, the notion that it's me who sees this and who sees this piece of paper, sees you. I have two halves of the visual field going to two cerebral hemispheres but I don't see it as two halves. There's a sense of continuity, unity of self, continuity of time, a sense of a golden thread going through the whole fabric of your experience, going all the way back to early childhood.

So all of these different aspects of self you might be able to tackle quite separately. For example that thread may be mostly frontal, another aspect of self may be somewhere else. Body image may be right inferior parietal lobule. So, there are different aspects of self. So just like we don't say what is life? In fact, I like Jim Watson's quip, he says "there are only molecules, everything else is sociology." It's going too far, but okay. But at least as far as life is concerned, biochemistry is concerned, we don't say what is life? There are all these different processes. Likewise for consciousness, it may be that there are different processes, and eventually we wont ask what is consciousness. The problem will just recede to the background. The other possibility is that there is one grand climactic solution such as DNA, we just haven't found it. So one has to be agnostic. One has to say let's look for potential important solutions to the problem of consciousness, not just assume its bits and pieces and we will solve each of these separately.

My answer – potential answer – is look here. Just as chromosomes gave you the solution to the problem of heredity. You wouldn't have solved it looking at proteins, collagen, other parts of the cell. The action is in the chromosome, Muller showed that and Morgan showed that. That led people to DNA, X-ray crystallography, and eventually to genetics. So I'm saying look here if you want to understand consciousness. Look at Wernicke's area which is unique to humans, look at inferior parietal lobule, to some extent look at right inferior parietal lobule, anterior cingulate, it's a fairly small set of structures. Their interactions – that's critical. And how that gives rise to metarepresentations of sensory representations, gives rise to qualia and a sense of self inspecting qualia. So short answer to your question, I gave you three answers.

BINGHAM: So function of the self would be?

RAMACHANDRAN: Well, the function of the self is as we said, one is a sense of anchoring. The other is a sense of, you don't want to be a disembodied self. Maybe some people do, but okay. The sense of anchoring, the sense of inspecting yourself to know that you are behaving appropriately, its multiple functions. But there's also a subjective sense of self. Me, inspecting something. People have said that it's an illusion, but if it's an illusion, you have to show how does the illusion arise. And maybe its not an illusion, maybe there's a scientific solution to the problem of the kind I just outlined. That is, you creating these meta-representations and how do you use these specific structures that I just talked about to create these metarepresentations and in turn create what we call meaning. We know that Wernicke's aphasics do not understand meaning. That's what eludes them. So if you want to understand what meaning is, that's a good region of the brain to look at. What is special about the microcircuitry there that generates this? And here we have Crick and Koch defend because they said don't look at the entire brain, there are specific structures involved. And I don't agree with them that there is a separate qualia problem and then there is the self. I think they are part of the same problem. But I do agree with them that don't look at the entire brain, that there are specific structures.

BINGHAM: How does the way you think about all this affect the way you believe – the way you act? In the sense that, if you have a cutoff where you are saying that most other animals don't actually experience pain, say, in the way we do?

RAMACHANDRAN: Well, this raises ethical dilemmas, obviously, my answer is that there is enough of similarity of the pain experienced by a monkey or an ape that I would be hesitant, because of my mirror neurons firing away or whatever, to cause it pain. But there is not enough reason to expect a planarian or a fruit fly to experience – not enough similarity that I would be worried about squashing a fly. So it becomes, as I said, as Francis would have said, when you understand these phenomena more clearly, what qualia is and what self is, then you can begin to make clearer – I can answer the question more clearly whether is it okay to hurt a planarian, and not okay to hurt a cat or an ape. Certainly not an ape, but which is what we said, okay to hurt a cat. Cat lovers would say no. but I'm saying these are subsidiary issues because it's like saying, abortion. When do you start calling, when is it unethical to kill an embryo? What if it's 8 months? What if it's 7 months? What if it's 6 months? So what I'm saying is its similar.

I want to argue that there are critical moments in evolution and I think something unique did happen 150 maybe 200 thousand years ago, to the brains of our apelike ancestors, to make you more conscious of your qualia, to contemplate and introspect on your qualia, on your pain, to an extent that its not possible even in a monkey. Now whether that justifies ethically terminating a monkey's life or causing it pain, you can't answer this question now because it may have some rudimentary semblance to the kind of pain you experience, that you don't want to do that. You don't want to cause it pain, or it may not, right? For now it is best to assume that it can.

BINGHAM: So if a dog yelps, do you think that's just a reflex?

RAMACHANDRAN: But look, I mean, humans can yelp without feeling qualia. I mean to put it really crudely, if I cut your anterior cingulate, and then I poke you with a needle, I don't know if its actually known if they would yelp but they would certainly withdraw their hand. They even say I feel the pain, but I don't feel pain. Its not agonizing. We have these words which are no longer valid once you get to the kind of analysis that I'm talking about. When you get to the nitty-gritty, then you can be more specific about how closely its pain, the dog's pain, resembles yours, and then you can make the ethical decision, is it okay to cause it pain? I would say no, right? But that may be my mirror neurons talking because I empathize with my dog. But you can't provide a scientific answer to that question yet.

BINGHAM: So you don't think there are any Bill Clinton dogs, you know, I feel your pain? Dogs that feel other dogs' pain.

RAMACHANDRAN: Almost surely other animals have mirror neurons, but people often ask me, if monkeys have mirror neurons, and you think mirror neurons are so important for culture, how come monkeys don't have culture to speak of? The short answer is, some of them do. But the real answer is, we are not saying mirror neurons are sufficient. We are saying something important happened to the circuitry there, that this is where the action is. And that circuitry, when it reached a certain level of sophistication, and made connections with certain other regions of the brain, some emergent property evolved. And that made rapid transmission of culture possible. This includes the activity of mirror neurons. They are central, playing a central role, but that doesn't mean that's all you need. Because monkeys have it, they don't have culture. I mean its like saying, wings evolved from forelimbs. We know that's true. But its like saying, if that's true, why cant monkeys fly? So it's the same kind of logic there.

BINGHAM: Some people would argue that other animals do have different kinds of culture.

RAMACHANDRAN: Well, yeah. But it's misusing the word. Any type of rudimentary imitation and transmission, you could say, that is a rudimentary example of human culture. But nothing like the sort of thing you see in humans. I mean it becomes a semantic issue, whether you want to call it a qualitative or a quantitative jump, and I think that genuinely emergent properties exist in the human brain which don't exist in rudimentary forms in the monkeys. In great apes, you might find some components of these emerging. So obviously I strongly believe in evolution through natural selection. I don't believe in intelligent design. It is odd that our president is championing the cause of intelligent design, given that his own existence is a living negation of this idea. Sorry, had to throw that in.

BINGHAM: Let's go back to your, now that we've dealt with a couple of those issues. Where, given that you described yourself as this child growing up as being a little bit socially isolated, and so on and so forth, what happened to end up with this sort of curious combination of scientific medical detective which must mean you have a reasonable bedside manner so that you can elicit trust from these various patients, and the showman? I mean, how do we get this combination?

RAMACHANDRAN: Well, the social awkwardness as a child, I think was actually helpful. Because what happens is it makes you withdraw into your private playground of ideas. And I would read lots of books about scientists and biologists. I was obsessive about collecting seashells and fossils and doing experiments at home. I used to collect seashells on the shore and was dazzled by the amazing variety, as I'm sure every adult is even to this day. And then I said what are these and why is this amazing variety, but then they fall into groups, and you begin to classify them. Then I went to the Madras library where you have this enormous eight-volume tome, about each book fully – each book about this big. They are all hand colored engravings of seashells. Going back to the grand old Victorian times, where one scientist spent a lifetime studying, classifying, and making pictures of seashells. And I would go through this and identify all of these seashells. So that's, often taxonomy and classification is the dawn of science.

At that time, they didn't even know about Darwin, when they were doing this. But they saw beautiful patterns of taxonomy, and so you sort of feel, and then you go and read some other book from 1850 and 1890 and I have seen libraries full of these books. And I have felt these were my playmates. They came alive in my mind. So, Reeve, whose book I am talking about, was my playmate. I was having conversations with him. Faraday was my playmate, Darwin was my playmate, Huxley was my playmate. So it makes you feel no longer socially awkward and bizarre or crazy or clumsy; it makes you feel that you have your own private world and you exchange ideas with these people. I know this sounds delusional, but…

BINGHAM: When did you upgrade from imaginary friends to real friends?

RAMACHANDRAN: Well that was sort of early childhood but I think once I started going to medical school and interacting with people, that well, some people say I'm still socially awkward but maybe not. Then I started interacting with people, I think that shyness went away, and I – I don't know about giving lectures, and I think that's a trick you learn watching other people to some extent – and maybe there are components of its that's really part of your innate personality. But going back to, sorry there's another question embedded in there that I'm missing, so sorry, you're talking about moving from social awkwardness to…

BINGHAM: Well there's the bedside manner and the showman, how do those…?

RAMACHANDRAN: That's not incompatible. If you look at again, going back to the 19th century, if you look at all these people whether Huxley or Faraday and all these people, if you'll pardon the sort of lofty comparison, but if you go to these people, they were doing nitty-gritty experiments most of the time. But when called upon to do so, I think the most important thing about being a communicator, again it hawks back to what I said about being passionate and excited. Somebody who's talking about Kashmiri shawls, how did it excite my interest? Its about you being – if you're not excited about something, you cant communicate it to somebody else. So you have to, first of all your story has to be clear, that's one thing, and secondly, you have to be excited about it. These are the two minimum requirements, and then you are a good communicator.

BINGHAM: So how does America come into this because, a lot of this is Victorian, its English, you're a fellow of All Souls, which is a quintessential Oxford college, Royal Institution, when did you come to the states, or when did your family come to the states?

RAMACHANDRAN: Well I mean I came to the states just for, its sort of good fortune and at that time there were not many jobs in England, and I got offered this position so I came here. Brief answer to your question, is I really enjoyed Victorian science, reading about it, because it's the dawn or the beginning of science. And science is most exciting in the very beginning when people are still tinkering, and playing around, and saying, what if I do this, what if I move this magnet in this coil, what if I sprinkle iron filings on a sheet of paper, what if I put my wife's hand in front of the cathode ray tube? It was not motivated by some deep insight, but you just essentially going on fishing expeditions, but you have to have intuition, because always there's a serious agenda underlying the playfulness and going after anomalies and that sort of thing. And science was a lot of fun. To put it differently, it was a lot of fun, during Victorian times, and it was a grand romantic enterprise and some of that is dying. Fortunately it is still not completely dead in England, but in the United States, I strongly believe, of course there are lots of exceptions, people who have this romantic vision, who are idealistic, who are still excited, but

I think very often because a nine to five job, you go in there and do something, and I think its partly the educational system, and partly it becomes a production line thing, an assembly line thing and I think the antidote to that, is to read a lot about the history of science, and hang around people who are excited about science, who are constantly passionate, who are enthusiastic, hanging around Francis Crick, hanging around Terry Sejnowski, hanging around Roger Bingham, you know. People who are excited about what they're doing, and I think that's a good recipe to become excited about it yourself, and not transforming it into a boring nine to five job.

BINGHAM: If you couldn't have been a scientist, just what would you like to have been?

RAMACHANDRAN: I would have been an archaeologist I think and/or a paleontologist because it has that same sense of going and looking at odd things, and actually like Schliemann going and looking at the Iliad and the Odyssey – the Iliad, and saying this is not a legend, there is Troy.

BINGHAM: So you're still staying in science, basically.

RAMACHANDRAN: Well yeah, if you want to call archaeology a science, that's true.

BINGHAM: No great passion to be a concert conductor, or something?

RAMACHANDRAN: No, but maybe a vocal musician or maybe a poet, writing poetry. I enjoy reading poetry, because the great thing about poetry, and literature of course, its one of a kind. In other words, if Darwin had died prematurely, it would have been another 20 years before Wallace would have worked it all out, maybe 10 years. I don't want to say Rosalind Franklin, and lets not go there, from Crick and Watson, but most discoveries in science, if somebody doesn't make it, it's a matter of time – 5 years, 10 years – they don't have that unique, even though as I said, it is a romantic enterprise, there's as much creativity in science as in the arts.

But the great thing about art is that each piece, each poem is unique. When Shakespeare says, "tomorrow, tomorrow and tomorrow, creeps in this petty pace," or when he says, when King Lear says, "when we are born we cry because we have come to this great stage of fools." That says it all, in my mind. That line is enough to justify Shakespeare's entire life. Forget about all the other plays, or the passage in Macbeth about "tomorrow, tomorrow, tomorrow." That's the great thing about the arts and about poetry and all of that. So to be able to do something like that, must be a wonderful experience. In science, you do experience joy in creating something, but you say if I hadn't done it, ten years from now somebody else would have done it.

BINGHAM: So what discovery would you like to have made?

RAMACHANDRAN: In science? That's a very good question. Many times you curse yourself and you say why didn't I think of that? That's one class of discoveries. Sometimes you say, I did think of it but I didn't do anything about it and that's when you really kick yourself. When I was in Cambridge, mainly doing physiology and medicine, things like that. And I said, I read somewhere, and this is common knowledge among medical students, if an asthmatic person smells a rose, of course he starts wheezing, the pollen gets in, he may die. Here is the interesting observation. If an asthmatic sees a plastic rose, he can immediately his lungs are going to spasm. The mast cells release histamine, serotonin and histamine and all of that. Its histamine I think. The bronchioles are going to spasm and you get an asthma attack and people say, it's conditioning. Remember this is long before immune conditioning was discovered. And I said, my god, if you can do this, why cant you play a loud sound to a rat, give it steroids to suppress its immune system, would you then just present the sound and the rat immediately suppresses its immune system? Or, why not give this asthmatic antihistamines every time you play a note? So he just carries this thing which produces a note in his pocket, and as soon as he sees a flower and starts wheezing, he plays the note and stops wheezing.

I said this to my physiology professor, David Whitridge and he laughed and he said it's a joke. But guess what, if I had pursued it, I would have been much more famous than I am now. I would have given birth to the whole discipline of psycho neuro-immunology, If I had just pursued that. Because somebody did that very same experiment ten or fifteen years later and found you can actually do conditioning of the immune system, and now there's a whole area of research. And its very important for things like, people used to think its all flaky mind body interaction and mind body medicine, now its all legitimate because of that discovery.

BINGHAM: This is in the same vein as when you were a child. Did you not try to see if you could persuade, what happened with ants if you sprinkle saccharine…?

RAMACHANDRAN: There are lots of little experiments. I still don't know the answer to this, maybe you know the answer. And that is, I was looking at ants going for sugar, everybody knows this, but the question is can you put saccharin and would the ants go for that? You know, would the receptors be fooled? It was my first psychophysical experiment. Would the receptors be fooled by saccharin just as your receptors are? Does the ant, despite six hundred million years of evolutionary gap, have the same sweet receptors as you and I do? I don't know the answer. The other experiment I tried, again I couldn't get it to work, was we know that tadpoles, if you cut their tail, they regenerate it. If you cut an arm, it regenerates. A human being, if you cut an arm it doesn't regenerate. If you could learn the trick, maybe humans would regenerate arms. What could be more important? A frog, after metamorphosis, if you cut the arm, does not regenerate. Now is that because it's a frog or because its older? How do you find out? So I put tyroerasol in the water, this blocks metamorphosis, so you get a geriatric tadpole, a very old, big tadpole with arms. The question is, if you cut the arm off, does it regenerate? The tadpole just died, I wasn't a good enough surgeon so I don't know the answer, maybe somebody knows, but it's a good question right? I mean, is it aging that stops it? Or is it the metamorphosis that stops the ability to regenerate? Yeah, anyway, I was fooling around with lots of little experiments of that nature.

BINGHAM: Who would you have liked to have had a conversation with? I mean, it could be alive or dead, mostly I'm thinking…

RAMACHANDRAN: Alive or dead.

BINGHAM: Well I'm thinking they're probably dead because I said who would you have liked to have had a conversation with.

RAMACHANDRAN: Well, I think 2 or 3 people; probably Thomas Huxley because he was a fascinating guy. Most people would say Darwin, because obviously, he was a genius and all that, but Huxley was not only a genius, but he was also fascinating; he was interested in all kinds of things. He was a great expositor, and he had a personality that I can relate to. He had a lot of pugnacity. Not me, but I'm saying, I like people like that. They're always fun to watch perform and its always fun to talk to them. So, Huxley would be one. Wallace would be another, given the experiences that he had. Traveling to Malaysia, traveling to uh... So the great explorers, I'd like to talk to the great explorers. Especially when there's also science mixed in, as was true of Wallace. So, Huxley, Wallace, of course Michael Faraday, what makes him tick, what makes him creative, but yeah, those would be the people I would want to talk to.

BINGHAM: I neglected to ask you one thing during the consciousness, when we were talking about consciousness. Which is, do you believe in, that is do you think we have free will? Do you think *you* have free will?

RAMACHANDRAN: Well, you know its funny you should ask that. Uh, I think, well you should ask Pat Churchland, who you're going to be talking to soon. Um, the answer is that.. The question is- there is determinism- how do you know? Ok I saw that I did that. Now, I have this distinct sense of picking it up, and if you give me two, an apple and a banana, ok I'll do that. And I knew I did it. So there are many components- I conjure up an internal vision of possibilities. That I can do this and I can do that- a sense of agency. And by the way, I think specific brain structures are involved. The inferior parietal lobule again, the supramarginal gyrus, is involved in enabling you to conjure up possibilities of movement. And that is undoubtedly a component of free will. I can do this, I can do that: possibilities. Right? The anterior cingulate is involved; we know that. When it is damaged, people say they are fully conscious, but I don't want to do anything! So they come out of this. They say, oh I knew what was going on, I just didn't want to do anything about it. I could hear you talking, I just didn't want to reply. They're just completely spaced out, you know, like potheads; same sort of complete and total lack of initiative and ambition. Not to debunk.

What was I saying, oh, free will. I do like an old argument, by the way, which is put forward by Don MacKay. Nobody else likes this argument, but I think it makes sense. It's a sort of Gödelian argument which says that, lets assume that my brain, for the sake of argument, was not a deterministic machine, because you know, chaos theory and randomness and maybe you have quantum mechanical effects spreading into the brain, a la Penrose, even though I don't believe that, but let's assume its like a billiard ball table. I see this, comes in, light quanta, eyes, goes through the brain, my hand reaches out like that. And even if I'm thinking about it and making a choice, a superscientist looking from above, watching my brain, could have predicted that, even though I think it's my will doing it, he could have predicted that. Let's assume that's true, that's the worst case for free will. So I say, ok, you're the superscientist. I believe in free will. Look at my, what's going on in my brain until the very last minute, last second in fact, write it down on a piece of paper. And then I'll make my choice and see if your prediction is correct. The answer is, it's always correct. Because you are a deterministic scientist, my brain is a deterministic system, and just before I make the choice, you've seen the cascade of chemicals and you say, I just predicted it before you made it. Therefore, you have no free will.

But, here's the crux of the argument: that prediction is only valid for you. Because the minute you show it to me, I can change my mind-if I am a human being, and I understand the meaning of what you've said. Again, the meaning is critical. Then I can say, my mind, and perversely say I'll do the opposite. It's because the very act of listening to you is going to change the validity of the prediction. The prediction is no longer true. Now you can say ok, I'll build that into the prediction. You can't, because it gets into an endless regress. Because if you build it into the prediction, you have to gain a new prediction, and again if you tell me the new prediction, yet again it changes the prediction. You could say, I could have an autocerebroscope, looking at my own brain events, right up to the last minute, and I'm watching it, and I say well I'm going to touch this. And I say, oh no, I'm going to change my mind, I'm going to touch this.

In other words, if you are a conscious agent, capable of appreciating meaning, then if a determinist scientist gives you a complete prediction, valid up to the last minute, that prediction is valid, in some ontological sense, only to that external agent. The minute it is internalized, that prediction is no longer valid. Its not that I can't, the point I'm making is, that I simply cannot make a prediction about my next future state. I can will it, but I cannot make a prediction. This is MacKay's argument, it's the only argument about free will in some real sense, that makes any sense to me, if you're a conscious human being. Every other argument I've seen supports the deterministic view. What if you say this randomness, it doesn't mean its free will, it just means quixotic, it means your behavior can be slightly flexible, it doesn't mean its free will.

BINGHAM: What about the stories that emerge from Ben Libet's experiments?

RAMACHANDRAN: Well I think as Churchland and others have pointed out, and Dan Dennett, it is, Dan Dennett and Churchland are eminent philosophers who have talked about this a great deal. These temporal paradoxes, briefly the Libet experiment is, you record brainwaves from the skull, the activity of the brain, when you're making movements. And it turns out, you ask a person, I'm going to measure these brainwaves, there's a thing called the readiness potential, a wave that occurs before you move your hand. So you ask this chap, in the next five minutes (I'm simplifying the experiment), but tell him, in the next five minutes, move your hand any time you want, a couple of times. And the chap just waits, and after 10 seconds or 30 seconds or one minute, he moves his hand. The astonishing thing is, you pick up the readiness potential almost half a second or more, prior to his moving his hand-prior to his internal sensation of having initiated the command. You know that because you can have a rapidly moving dial on the clock and you ask him when he initiated the command. And he says, yes and he remembers the time he initiated the command, and you find, that your brain activity has been recorded 30 seconds earlier. So if his will came in 30 seconds later, how can the will, quote unquote, have been responsible for the hand movement?

It must be an illusion, because it's a post hoc delusion or rationalization; because the brain event was picked up prior to your sensation of will, it's not time-locked. But these temporal paradoxes of will can occur for all sorts of reasons; it's not any more mysterious. It's because the event timing of the brain and what you pick up versus your motor command, there's no reason they should be precisely time-locked. There's a smearing of space-time when you move, an event, there's no reason that the subjective sensation should precisely coincide with your internal sensation. That's where I think there is a flaw in his logic.

But it raises an interesting question, and we've tried to set this up, and we may indeed set it up in collaboration with people at the Salk. What we're going to do, is to take this readiness signal and in real time display it to the person. And we'll tell him any time you feel like it, wiggle your finger. Now, the trouble is, you can display that signal to him .5 seconds before he wills it. Now what the hell is he going to say? He sees the thing on the screen and then his hand does that. Now is he going to say, there are only 3 possibilities. The machine has ESP, it's predicting what I'm going to do. I don't have free will. My god, I'm locked to the machine. Or he is going to postdate the events; he's going to say, what do you mean it happened before? It happened after I sent the will. So all the 3 possibilities can happen; it will be very, very interesting empirically to see what happens. It'd be wonderful if I convinced people that they don't have free will. The machine is controlling everything, you are just a puppet in a deterministic world. How would that affect your world view?

BINGHAM: One last thing, how does all of this that we've talked about map onto your background? I mean, you've talked about the veil of Maya, the whole notion of illusion, come from a country that wears Advaita Vedanta, the notion of…

RAMACHANDRAN: Well a couple of things, given my background, I'll get to the mysticism bit in a minute, but just in terms of style of doing research, my training in medicine I think helps a lot. Because what happens, you might say medicine is completely unrelated to doing research on psychophysics, well it's related to neurology obviously, but what I do is nothing like routine clinical neurology. So how did I get here and how is it useful? One answer is, it's useful because you're forced to, especially what I was trained, my initial training was in India. You see patients, at that time you didn't have any imaging technology, in fact you couldn't even get a blood panel very quickly, so you're forced to use clinical acumen, clinical ingenuity. And you really have to be like Cheryl Combs, you have to just use a few signs to figure out what's going on in the patient and if you didn't do it quickly enough, they'd be dead or very sick.

For example, and my favorite example, is appendicitis. And these days we diagnose it very quickly. But in the old days a guy just comes with lower right quadrant severe pain, vomiting, fever. Already you know, maybe its appendicitis, and if it is, you have to remove it. Because if it bursts and spills its contents, you get peritonitis and you die. But how do you know he has appendicitis because a number of things can produce those symptoms. You ask him, tell me about the pain. He says the pain started in the umbilicus, in the belly button, and then, funny doctor, it moved to my lower right quadrant. That only happens with appendicitis. And the reason is in the embryo, the appendix was right here under the belly button and then as you grow up and the intestines get thrown into folds, it gets pushed to the right lower side. And your brain doesn't know that. It still thinks the appendix is sitting there under your belly button. So you mislocalize it there. And then, when the appendix becomes completely inflamed, it irritates the abdominal wall, then of course you correct the mislocalization and say it is here. But this migrating pain… Then you do another thing, you just press him on the left side. You press him on the right side and of course it's painful because you're compressing the appendix, but if you press him on the left side, he says ouch! And it hurts him on the right side. The reason it turns out again, is paradoxical. You're displacing the gas in the colon, along the trans of his colon, and then expanding his inflamed appendix so it pains here. Now you see those two things and immediately schedule surgery. So this shows, without any equipment, if you know the right thing to do, you can diagnose very quickly. Now that's sitting in your brain, that its all about simplicity of experiments and knowing what to look for, rather than high-tech and deep insight and all of those things. Those come later. That's number one.

Now going back to mysticism, so you asked about my background, second we're going to mysticism. All of Indian philosophy is all about consciousness. Is there a soul, is there a mind? What is mind, what is soul, who are you, how did you come to be? They're obsessed with this. So are the Greeks, by the way. Now, you can't see a patient in neurology without confronting these very questions. What do you mean by self? How come this guy is saying, "I'm dead"? A disorder called Cotard's syndrome- I'm not alive, I'm dead. He's not crazy because he'll play chess with you. Everything else is fine but he says he's dead and he's absolutely convinced he's dead. In fact, you can take a needle and say are you sure you're dead, and he'll say yes. Do dead men bleed? He'll say of course not, no. Poke. And he starts bleeding. Well? I guess dead men do bleed after all. So that conviction stays in your brain. How does that happen? The self is often inconsistent. You say this is my arm… no sorry. I show you your arm, you have a right parietal lesion. Dr., that's my mother's arm. If that's your mother's arm then why is it attached to you? He just stares at you; he won't answer that question or he'll confabulate, he'll say, I don't know, my arm is behind me somewhere. He'll make up a story.

Now people think this is something very spooky and strange, denial, but in fact, its very common. Maybe I've told you this before, but we do this all the time in our daily lives. For example, to give you a frivolous example, if you ask people what is their IQ, is it above average or below average. Ninety eight percent of people will say it's above average. In fact they'll say it's well above average. Now this is mathematically impossible because it is a Gaussian distribution. In fact half the people are below average, scary thought. Half the people of this world are below average in intelligence, but they are in denial about it! They refuse to accept it. This is painfully evident in our recent presidential election by the way. So denial happens all the time in our lives.

So what I'm saying is if you were raised in India, you are confronted with questions about the mind all the time, but all of it is quite mystical and some of that must have spilled over into my thinking about neurology and consciousness and mind.

My interest in it, my approach, of course, is completely empirical and scientific and hard-nosed. But speaking of that, there is one question I think which is really metaphysics and not science or neurology. And that is the question of, this is an objective world, the thousands and millions of people. But I have this sense that I am me and I am special and I am expecting the world from this point-this little tiny flicker of light in the whole space-time manifold. Einstein was puzzled by this. He said the notion of here, now, me, is not there in physics, it just doesn't exist. And that's a problem in metaphysics and of course it's intimately linked to the sense of self, the idea about souls, things like that. No less a person than Kurt Gödel, the greatest, arguable the greatest logician of the century, was puzzled by this problem. He said, who is me, who is here, what am I and what is now. It is not there anywhere in this space-time manifold, this little spot. So that had nothing to do with brain, consciousness and all that, but Schrödinger, wrote a book. Half the book deals with this problem, so I think there is something important there which most scientists and physicists don't know about and don't care about.

BINGHAM: What would your advice be to a young scientist? I'm just remembering Sir Peter Medawar's book…

RAMACHANDRAN: Well I would say a couple of things. There's no recipe obviously. It depends on your personality. But several things, one thing is hang around people who are exciting and passionate about what they do because it is very contagious. Avoid like the plague, pedants and people who are just engaged in drudgery. Hang around creative people, enthusiastic people and because passion is contagious as I said. Read a lot about the history of science. There's a misconception that people when they retire and are old fuddy-duddies, then they start reading about history. There is some truth to that, but I think young scientists, people that are getting into the field, if you read history about how discoveries were made, it has two functions.

One function is, you emulate the style of those scientists you're reading about. And it's not surprising that most Nobel prizes are won by people that were students, disproportionate numbers of Nobel prizes are won by people who were students or grand-students of Nobel laureates. Now the cynical view of this is the old-boy network, but I don't buy that. I think that it's because you emulate the style of people. So hanging around people who are enthusiastic or quote-unquote great scientists or reading about the discoveries and how they were made serves the purpose of you emulate their style, A.

B, another reason for doing it is it makes science more fun because it puts your enterprise in context. Its not me, trapped in this narrow cul-de-sac, doing all these measurements, which you need to do, obviously. But you have to avoid the cul-de-sac phenomenon which is very pernicious and very common in modern science. You feel comfortable in this little cul-de-sac, you get rewarded because you send this paper off and the reviewer, in your own little field, says oh it's a great paper, and it gets published in your own specialized journal, and this is human nature. You have this club and other people in the club think you're great and you engage in this mutual admiration and back-slapping and that's the death of science. If you want to do science, get out of the cul-de-sac. Of course, you have to periodically re-enter, make careful measurements, be worried about what your colleagues are thinking. But what's much more important is to get out of the cul-de-sac, look at the whole history of science, look at what you're doing, giving it a sense of perspective.

So these are the two things, I would say. Read widely, things completely seemingly unrelated to your work, that's A, because novel insights come from interdisciplinary cross-fertilization of ideas. Whether its DNA, you know Crick jumping into exitocrystallography, I can think of dozens, of hundreds of such examples. Read widely, hang around people who are passionate and enthusiastic, and very good at what they are doing, jump outside your cul-de-sac, and read a lot about history of science.

BINGHAM: The next generation is coming along, I gather. I was reading in the San Diego newspaper recently that your son, apparently in typical Rama fashion, got an absolutely perfect score on his SATs.

RAMACHANDRAN: He did indeed.

BINGHAM: And by reading them a couple of weeks before he had to take the exam.

RAMACHANDRAN: Yeah well thank you for raising that. I mean, he is a very bright kid, but he was very erratic about 2 or 3 years ago. He is now 16, and you would get outstanding grades in some classes and poor grades in other classes, but I knew he was smart because he had a great sense of humor. My wife is American and she enjoys camping a lot and she said, so lets all go camping. And Mani isn't very outdoors, and he said, "mom, the reason mankind invented houses was to avoid camping." This coming from a 13 year old, I thought was pretty smart. So he's very creative, always knew that, but neurotic and sometimes moody. People said don't worry, you know, that's just typical teenage stuff. He still does that, but he's very smart, writes poetry, imaginative and all of that.

But, by the way, on that note, my younger boy who's twelve brings his homework and insists I do it all for him. He brings us books on science and I say ok I'll help you with the homework. They are the most incredibly boring textbooks you can find. They are nothing like the textbooks I used to read as a child. And I'm really trying to make a political statement here. I look through these books and its all about how you recycle fuel and oil and all this and very little about basic science, nothing about Faraday, nothing about sprinkling, nothing about radioactivity, all that exciting... I'm not saying only basic science is exciting, but it's all about the weather and the climate and you know, recycling waste. There are about three chapters on recycling waste!

I read it and I say, how can this kid, my second kid is smart too, no wonder he finds it absolutely boring! And then I discovered, I read an article by Feynman on precisely this question. He was appointed to a board to judge which textbooks should be used nationwide, which is in itself peculiar. Why should that one textbook be for the entire country, it's bizarre. And he sat on this board and its all about publishers coming to him, wining and dining him, phoning him, telling him even that they would arrange a call girl for him, can you believe this? This is there in writing in his book! Saying, adopt our textbook, it's a great textbook. And he realized this is not because he is Feynman, they were doing it to all the board members. And he says this is highly unethical. This is the sort of thing drug reps do to physicians all the time and it still continues. And then there's this tendency to homogenize the text book, make it completely boring, and what drives it is the book publishing industry. This is most unfortunate and needs to be corrected.

BINGHAM: You are obviously not feeling very passionate about this at all.

RAMACHANDRAN: I'm sure many will agree with this.

BINGHAM: So, I think that what we have here is an N of one in Ramachandran. Do you wish you had whole generations of students like you, following you?

RAMACHANDRAN: Well, I mean it's up to them. I have a few students who not only emulate my style but my mannerisms- that's spooky. But the thing is, what I would say in response to that is that every student has to develop his own originality and style. To some extent, yes of course, you want people to follow up on your research and maybe even emulate aspects of your style, and I try to convey the enthusiasm and style of doing research to other students. It rubs off sometimes. Sometimes someone has a completely different style and does outstandingly well. So, you know, it's important not to classify the person or try to make the person emulate you.

BINGHAM: What's next for you? What's the next piece of research you're working on?

RAMACHANDRAN: Well again, that's very hard to answer because the kind of research I do is often opportunistic. Here's some strange thing, let me pursue it. But I'm very interested in higher functions in the human brain. We talked about what makes the human brain unique, I talked about culture. There are interesting things like mirror neurons, and there's been a lot of physiological work, but what we want to do is design perceptual psychological experiments to test the functions of mirror neurons. And then look at neurological dysfunction in terms of what's happening to mirror neurons. So this leads you to higher functions. For example, how do we engage in abstraction? People think of intelligence as one thing, IQ tests. Or at most 2 things: verbal IQ and spatial IQ. This is ludicrous because, you take the liver. The liver has 30 functions, each of which is quite distinct and each of which can go wrong. There's bile secretion, there's glycogen storage, dozens of functions, enzymes to portal blood flow, detoxifying portal blood, all kinds of things. Can it be that the brain, which is vastly more sophisticated, especially in humans, has one thing called IQ that you can measure? It's absolute idiocy. So there are lots and lots of functions, higher functions, which are probably unique to humans, like attaching meaning to things. Abstract symbol manipulation-how do you manipulate symbols in your head, offline.

How do you do transitional logic? If A is bigger than B and B is bigger than C, then A must be bigger than C. Is that because through hundreds of instances of induction, you've developed deductive logic? Because every time you saw A bigger than B and B bigger than C, A turned out to be bigger than C? Probably not. Is there some other algorithm and how is it instantiated in your brain? What parts of the brain are involved in this type of reasoning? So we're looking at Wernicke's aphasia-patients who don't have semantics of language. Do you need language, whether syntactic language, or semantics, or comprehension to make transitional statements-A is bigger than B, B is bigger than C, therefore A is bigger than C.

Obviously you can do it verbally, but there is this whole theory in psychology, Whorfian hypothesis, that you need language to think. So here is a simple way of testing it. And others have done this too, by the way, but the way we're tackling it is looking at people with very discrete brain lesions who have lost functions and see can they do transitional logic. And the challenge there is how do you do it without using words? You have to do it non-verbally. So this explores the interface between language, on the one hand and thought on the other hand. Things like meaning, consciousness, language, thinking-all the big questions, are tackled by looking at people with damage to different parts of the circuit, especially the circuits I mentioned earlier-Wernicke's area, inferior parietal lobule.

You already found a region on the left side of the brain which seems to be involved in metaphor comprehension. You wouldn't have suspected this, but when that's damaged, left inferior parietal lobule, people have a great deal of difficulty with interpreting proverbs. They talk to you normally, they play chess with you, their IQ is normal in most respects. Then you ask them- "All that glitters is not gold," what does that mean? And the chap says, well what would you say? You would say, don't be deceived by appearances. This chap says, oh well you know, just because it's shiny and glowing doesn't mean its gold, it could be copper. And I said, yeah I know, but is there a deep meaning beyond that, can you take it further? And he says oh yeah, it means if you go to a jewelry shop, you have to be very careful because the guys are out to rip you off. What you have to do is you have to take the specific gravity so you can know if it's really gold and not copper. So he's not stupid, he says take the specific gravity and da da da, etc. And this is typical, you can give him 10 proverbs and he always latches on to the literal meaning.

Now when you send it to a journal for publication, the referee said, oh well how do you know they're just not bright, they can't talk, whatever, that they're stupid and don't understand the question? Well its obvious, because when you give it to them, they clearly understand what you're asking because they often give you elaborate, convoluted, even ingenious interpretations of the proverb, but completely missing the point. A bit like the people who review my grant proposals…

BINGHAM: On that note, perhaps you can come back another time and tell us about the results of all these experiments.

RAMACHANDRAN: Sure I'd love to.

BINGHAM: Thank you so much.

RAMACHANDRAN: Thank you.

BINGHAM: Ramachandran.