

# BRAIN SCIENCE PODCAST

*With Ginger Campbell, MD*

## Episode #39

### Interview with Dr. Michael Arbib on Mirror Neurons

Aired June 13, 2008

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#### INTRODUCTION

This is the *Brain Science Podcast* – the podcast for everyone who has a brain – and I’m your host, Dr. Ginger Campbell. On the *Brain Science Podcast* we explore how recent discoveries in neuroscience are unraveling the mysteries of how our brains make us who we are. For more information including Show Notes, links to previous episodes, and information about how to subscribe please go to the website [brainsciencepodcast.com](http://brainsciencepodcast.com). We also have a Discussion Forum at [brainscienceforum.com](http://brainscienceforum.com), and you can send me email at [docartemis@gmail.com](mailto:docartemis@gmail.com).

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**GC:** Welcome back to the *Brain Science Podcast*. This is Episode 39. Since my voice is not very good today I’m going to try to get right into today’s interview with Michael Arbib from USC. This episode is really a follow-up on Episode 35, which was about mirror neurons. However, if you’re new to the podcast I think you’ll do fine if you just listen to this interview and go back and listen to Episode 35 afterwards. It’s not necessary to listen to Episode 35 before you listen to this episode.

As I mentioned, this is an episode about mirror neurons, and in particular Dr. Arbib is well known for his Mirror System Hypothesis about the role of mirror

neurons in the evolution of language. So, this also relates to some of the other episodes we've had about language. I'll get on into the interview and I will be back with a few brief announcements at the end.

One thing I have to tell you about this interview is that there was a little bit of a hum on Dr. Arbib's phone line, and the best way to listen to this episode is to listen to it with your volume at the lowest level that you can hear comfortably. If you do that the hum won't be very loud. If you crank it up I think you'll find the hum to be very annoying. So, this is going to be one you'll want to listen to on relatively low volume.

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**GC:** I'm very proud today to have Michael Arbib on my podcast. Michael, thanks so much for coming on the *Brain Science Podcast* today.

**MA:** My pleasure.

**GC:** I asked you to come on the show so we could talk about the mirror neuron system, but I thought maybe you might start out by just telling my listeners a little bit about yourself and your background.

**MA:** Well, very briefly, I've always been interested in the interplay between understanding the brain and building intelligent machines. A particular focus of that has been the role of vision in the control of movement. How do we look at the world, and look at it not just in terms of seeing what things are but how to interact with them? How do I look at a cup, not just to recognize the cup but to figure out how to move my hand to grab the handle, and bring the cup to my mouth, and so on?

And I've worked with many experimentalists—I'm more a computational type—but many experimentalists with creatures like frogs, rats, monkeys, and humans.

Some years ago I was on a collaboration with Giacomo Rizzolatti in Italy, Hideo Sakata in Japan, and Marc Jeannerod in France on the issue of what goes on in the brain of a monkey or a human as they control their hand movements, or as the brain controls hand movements. And that was when Giacomo Rizzolatti discovered mirror neurons. These are neurons in the brain of the monkey that are active not only when the monkey is doing something but when he sees a human or another monkey do the same thing.

And we then at my university—University of Southern California—did brain imaging experiments to see if there was something like a mirror system in the human brain. Lo and behold it turned out that an area of the human brain that got active when we had people both do something with their hands and see somebody else do something with their hands was Broca's area. Broca's area is a language area, and so the mystery was why should a mirror system for grasping be in a language area. And that's where I think the topic of our conversation really gets started.

**GC:** I have to ask you—because I've read a lot of different descriptions of the discovery of mirror neurons—were you at Rizzolatti's lab when this happened?

**MA:** Not on the exact day. We had this collaboration, so people from Parma in Italy would come to my place in Los Angeles and I would go and visit them. But the actual day that they first got excited about this cell lighting up that they were studying – they were studying the cell to see how it responded as the monkey itself did things. And I'm not quite sure whether this was really the first time. But anyway, on one occasion Leo Fogassi, an important member of the group, was rearranging things on the tray in front of the monkey and the cell which had been connected to an oscilloscope through an electrode suddenly started buzzing. And so, that began more systematic investigation. So, no, I wasn't there the day it happened.

**GC:** And the story about the ice cream cone is also probably not exactly what happened either, although it makes a good story. You've heard that one? The story is that a graduate student or somebody in the lab was eating an ice cream cone, and the monkey was hooked up, and they noticed that the neurons were firing. That's one story I read.

**MA:** Yes, it may be true, but I can't vouch for it. I'm sorry.

**GC:** So, your background really started out in engineering?

**MA:** Well, actually mathematics. I, as a high school student and the beginning of my university days, was very much interested in pure mathematics. The turning point was somebody gave me a book called *Cybernetics* by Norbert Wiener, who was a great American mathematician who had been looking at things like feedback and information from a mathematical point of view, and then showed that the theory which had developed with applications for engineering also could be applied to the study of the brain. And I got hooked, and so instead of thinking of mathematics as just a source of pure aesthetic beauty I became interested in it as something you could apply to study the brain.

**GC:** One of the things that has struck me as I've been doing my reading for this podcast is how important interdisciplinary work is to advances, at least at the stage that we are now. And that's why I'm asking you these kinds of questions about your background and what you're doing, because I'm trying to communicate to my listeners that there are so many people working from different angles on the problem. So, I thought you might explain what computational – is it computational cognitive neuroscience? I mean what do you call it?

**MA:** Well, these are two different things which intersect. So, computational neuroscience is two different topics, really, which come together. So, it's either

how do I understand the brain: well, I can think of it as a computer. Oh, but it's not a computer in the sense of the computer on your desk top or your laptop. So, what is it that it has in common with computers—what's special about it? And there we get into what I call cooperative computation—that most of today's computers that you buy are serial computers. They have one thing going on at a time, they have very explicit programs which say get this information out of memory, process it, make a decision, OK, put the answer back here, choose your next data from there, and so on. So, it's very strictly guided by a single stream.

That's beginning to change now as people think more in terms of networks. But that's the classic model. The brain is more like competition and cooperation. You've got maybe some neurons over here are beginning to make sense of part of your visual input but some other neurons are coming up with a separate interpretation. And so, one sends inhibitory signals to the other and in the end they settle on an interpretation. But meanwhile you're already acting, and so the new information you get as you interact with the world changes what is going on. And, of course, what happens triggers various memory stores. There's not just one memory, there are many different types of memory for different sensory aspects, and so on, and so on, and so on. So, trying to think about this idea of the brain as a computer, but a very different computer; and a particular computer that's constantly learning.

And the other side of computational neuroscience is the computer now is such a powerful tool. We use it to record the data we get when we do experiments studying the brain, we use it to process those data; though to make an understanding of the brain we need to come up with new ways of using the computer to analyze data in different ways to understand the causal interactions in the brain. Whether we think of the brain as a computer or not, we still need new computational strategies to keep track of so much complexity. So, that's computational neuroscience.

Then cognitive neuroscience is how do we link the brain to the way we understand the world, the way we know the world—to our cognition. So, in other words, somebody might study the brain purely in terms of here's some damage to the brain—let's say Parkinson's disease—I want to understand how dopamine is related to both the normal functioning of the brain and the dysfunctioning of the brain, then maybe I can come up with a new therapy. There's nothing necessarily cognitive there. You're trying to restore the functioning of a circuit. Or you might try to say what are the memory mechanisms in the brain. Or you might be interested in how does the brain control the spinal cord to control the muscles. So, there are many topics in the brain that are not related to how we know the world. So, cognitive neuroscience is more visual perception, memory, when we're not talking about what is the detailed cellular activity so much as how the interaction of many, many cells lets us recall an episode or learn a new skill and so on.

And then computational cognitive neuroscience is my thing, where you bring the two together to say, OK, I want to use computer metaphors and computational modeling to understand how it is that we as humans come to know the world. And that again involves collaboration with people in many different disciplines, because I'll both be working with brain imaging of humans and I'll be working with people studying monkeys, and then to try and get down to mechanisms we may be working with very talented chemists and others who will have been looking at the very finest details of how one neuron interacts with another.

**GC:** So, do you think that for what you do being able to synthesize the work of a lot of different other people is an important skill?

**MA:** It's certainly a non-trivial skill. I think we've really turned the corner now in the sense that there are always skeptics when you talk about interdisciplinary work—those who feel that they have a discipline and that others are in some sense irrelevant to it. But what's interesting is that to the extent that I'm

interdisciplinary—namely computer science and neuroscience, leaving mathematics aside for the moment—both of those are themselves the result of crystallization from other disciplines.

When I was younger there was no such thing as neuroscience. There were anatomists who studied the brain, physiologists who studied the brain, chemists who studied the brain, and their disciplines were anatomy, physiology, and chemistry. And it was a big turning point to bring all those people together and say there are so many challenges with the brain that although you need to bring the expertise of those older disciplines, you're going to be united in future not with people from anatomy, if you're an anatomist, but with other people studying the brain.

And so, that's really been a corner turned. And now we have another corner that a particular group of people are now saying the challenges of the brain are such that it needs a new interdisciplinary grouping; not one that will break away from the rest of neuroscience but we'll certainly see an increasing number of people involved as a subspecialty of neuroscience: namely this bringing together of computation, cognition, and the careful analysis both of human brain imaging data, human pathological data, and the things we can learn from animal studies.

**GC:** It just seems like there's just so much information that it must be a challenge to find the right balance between interdisciplinarians staying in a narrow area that you can really feel that you have a mastery of.

**MA:** Well, I have a feeble joke which I tell to our first-year graduate students. I'm chairman of the curriculum committee for neuroscience at USC, and we just redesigned the whole graduate curriculum. We start with a one-semester course where we try to take our new graduate students and give them a sense of the whole range of neuroscience all the way from the molecular level to the cognitive level. And I point out to the students that the annual meeting for the Society for

Neuroscience now attracts about 30,000 people, most of whom are presenting posters or little talks. And so, since we have 30 lectures in the course, I said we have to go through 1000 topics per lecture.

And of course it's not something we attempt to do, but it does give sort of concrete numbers to the opinion you were expressing about how overwhelming it is. And that's the challenge, in a sense, of my approach to the redesign of the curriculum. We have to combine in some way an appreciation of how broad the topic is of neuroscience so that students are prepared to join multidisciplinary teams in the future. And yet, at the same time, each student has to find their own very, very, very focused expertise so that they can really get to the heart of some mechanism or process rather than just getting lost in the immensity of the topic.

**GC:** Right. I appreciate you taking time to go through that because actually I have listeners of various ages, including people that are thinking about what they want to study in graduate school and things like that. So, I like to get information out that might be helpful to them. Is there anything else that you think we need to discuss before we jump into the mirror neuron system in more detail?

**MA:** No, I suspect that if we do have anymore background it will come up naturally as you ask some neat questions.

**GC:** Great. So, I wanted to focus specifically on applying the idea of mirror neurons to language, and your Mirror System Hypothesis. So, would you like to just tell us about that hypothesis?

**MA:** Yes. Well, as I mentioned before the root of it is really this observation that monkeys have mirror neurons, and in particular they have them in a region in the front of the brain which the Italians call area F5, which is the fifth area that they numbered in the front of the monkey brain. And that when we went to record humans we could not record at the level of single cells, but we could look at how a

lump of brain lit up more in the scanner for whether the person was looking at actions or doing actions. And then there was an area that lit up both of these, and it turned out to be in Broca's area, a language area. Which, actually on other grounds, part of Broca's area does seem to be the homolog—the evolutionary cousin—of area F5. So, that immediately raised the question of why would a mirror system for grasping be in the human brain related to part of the language area.

And at first that didn't make sense. But quite a few years before I had visited the lab of a woman named Ursula Bellugi at the Salk Institute in La Jolla, California. She had been studying sign language, but in particular she had been studying people who had brain damage, and was trying to understand to what extent the brain of a person who uses sign language is like the brain of a person who uses spoken language. And she had found that, of course, if you're in the periphery you have to be able to see to use sign language and you have to be able to hear to use spoken language. But what she found was that as you moved, as it were, to the center of the brain, the areas whose damage would impair speech in the brain of a person who speaks were the same areas of the brain as would impair the use of signed language in a deaf person.

And so, that gave me the insight that where a lot of my colleagues were talking about Broca's area as the area for the production of speech, I could instead stand back and say we know the brain is adaptable enough that mechanisms that are used for language can, through the development of the individual, either become more specialized for speech or more specialized for sign language, or in fact many people can do both. So, that immediately said let's look at the problem of why is there a neurosystem for grasping linked to language in the human brain by saying let's break away from using the word 'speech' when we talk about language and use the word language more generally.

So that's, if you will, act one. Then act two was to notice that there is a community of people thinking about the evolution of language which includes but is not limited to people who are interested in the deaf, which suggests that maybe in evolutionary terms as we go from our distant relatives who are our common ancestors with monkeys 20 million years ago, to our distant ancestors who are our common ancestors with the apes 5 millions ago, and so on up the evolutionary tree, maybe the beginnings of language were not spoken but were in fact gesture. And we observe today that we all use gesture as we speak, so it's very natural that we have an integrated system for speech and gesture.

But the suggestion was maybe we started from being able to use our hands to act in the world, other early people—or, not even people yet—were able to observe our actions and imitate them, and so that gave an evolutionary advantage to creatures who could imitate. And I'll come back to mirror neurons imitation in our later conversation. But then the notion was that once you had this ability to create gestures and have them recognized, then they could become more useful for imitation not as a way of learning about practical skills but of learning about communicative gestures.

And so, we would get to something which I call proto-signs: the ability to use a limited number of gestures in a rather flexible way for communication. And then the suggestion was that only later did vocalization become married to that particular form of communication and yielded proto-language which combined speech and gesture, and then finally we're on our way to become the modern humans using language as we are doing now.

**GC:** Then the basic idea is that the mirror neuron system made it possible for us to develop an ability to gesture, and then communicate by gesturing, and then eventually to develop language as we know it.

**MA:** Yes, that's the simple form.

**GC:** Right. I just thought it might be good to start with the simple form and build on that.

[music]

**MA:** That's the whole thing about mirror neurons, is that a lot of the excitement is based on taking the simple form and then making it do everything. And I think everything you said is correct and it's a very good summary. But let's just see why, if we take exactly that, it's misleading.

**GC:** OK.

**MA:** Because what happens is it sounds as if mirror neurons somehow do it all. There are these mirror neurons and then they take on the task of imitation and suddenly they're doing language as well. So, the first observation is that our whole starting point was the mirror neuron system in monkeys. Monkeys have these mirror neurons but they don't imitate very well at all, and they certainly don't use language. They have some calls, but chickens have calls as well. So, having little calls that mean something to other chickens or other monkeys is not language.

So that the slogan I use that describes a lot of the work I've done since the early collaboration – the sort of first statement of the Mirror System Hypothesis, I should say, was jointly with Giacomo Rizzolatti, who was the leader of the group that discovered the mirror neurons in Italy. And we wrote a paper in 1998—or we published it in 1998—called “Language Within Our Grasp” which sort of summed up what the point was in terms of looking at grasp and gesture rather than vocalization as the key to language.

But, having said that, the issue is how do mirror neurons yield language, and the answer is mirror neurons by themselves don't. And so the slogan that I have is “Beyond the Mirror.” It's to say, yes, mirror neurons are a central component of

the story, but to understand it fully you have to go beyond and say how do mirror neurons work with other neurons to do what they do for the monkey. Now, apes have some ability for imitation that's much bigger than that of monkeys, so is it the mirror neurons that changed or, more likely, is it that the network of brain regions of which the mirror neuron is part changed? And then, again, what further changes take us from an ape-like beyond the mirror system to a human system?

Well, I'm sure most of your listeners know about Kanzi, the bonobo, and others who have been taught the use of either sign language or, in Kanzi's case, lexigrams—a little bit like refrigerator magnets—to what are the meaning of these particular symbols; put them up on the board and you can convey a request or an observation. But Kanzi, the bonobo, is basically stuck in terms of how many words he knows and how much he can put them together—what a two-year-old child can do. And the three-year-old child leaves Kanzi in the dust in terms of the size of the vocabulary and the subtlety of the ways that the words can be put together. So that, again, something changed in the underlying nature of the brain. The mirror neurons are still there, they're still working for grasping, now they're working for recognizing words and so on, but somehow they're part of a larger system that can handle the semantics and the syntax—the amazingly rich structure of language.

So, the quest has been to say that on the one hand let's use this discovery of the mirror neurons to provide, if you will, a grounding center for our exploration of the brain and comparing monkeys, apes, and humans, and yet at the same time to keep remembering mirror neurons by themselves don't do imitation. They don't do language. The mystery is what are the larger systems of which the mirror neurons are so crucial a part.

**GC:** Forgive me if I'm oversimplifying again, but the first thing is that imitation is something that requires more than just the mirror neurons, since the monkeys have mirror neurons but can't imitate?

**MA:** That's right. If you look at some very simple behaviors, the monkey does imitate, but if you go in and say what is involved in this imitation it might be something like – Here's one experiment: you show a monkey a jar with some food inside. The monkey will grab the jar and start trying to get at the food inside and eventually will pull the lid off. If you show the monkey that you can use your jaws to work the lid off, then there's a much higher probability the monkey goes from being very unlikely to use its mouth to remove the lid to being quite likely to remove the lid. So, you can say that's imitation, but what the analysis that we accept says, this is priming; or it's just saying, 'Hey, think about using your mouth.'

So, it's not, 'Look at the details of the behavior and see how to solve a problem by attending to the details.' It's just like a hint, which we call effector priming. It says, 'You were looking at this problem purely in terms of your hands, think of the mouth.' And then you see why it's not imitation, because if there were some way you could just, as it were, jazz up the part of the brain of the monkey that uses the mouth, then you would have gotten exactly the same change in behavior. It didn't require observation of the detailed action to be able to imitate it. In other words, you don't need a mirror system that's recognizing specific actions to make that form of imitation work.

**GC:** When we get to the chimpanzees they have some limited ability to imitate, but again, they don't imitate details.

**MA:** Yes, so our favorite example is a guy named Richard Byrne from St. Andrews in Scotland, but he spends time with his students in Africa observing gorillas. And gorillas have some fairly fancy feeding behaviors. For example,

they eat nettles, and nettles have little spikes all over the leaves and if you were just to try to pick them with your hand you'd get these spikes in your flesh, and if you tried to eat them you'd be in trouble. But these creatures are able to grab the leaves and the stem in such a way that they don't get damaged, and then to fold the leaves in such a way that they make a nice little bundle that finally they can pop into their mouths and eat without damage.

And it seems pretty clear that young members of the community do get this skill through observing the adults who already have it. But it takes them years to be able to do this rather than what we would do, which is we would get the idea probably in three or four observations. And we might not be very skilled at doing it after that and we'd have to practice before we stopped getting those pesky spikes in our hands. But we would, as it were, get the idea and show by our behavior that we understood the basic idea very quickly. And so, that's again a dividing line. There is that imitation but it has a much larger component of trial and error.

So, I think the idea that you can look at a behavior and dissect what are the goals, what are the ways of approaching the goals, and get immediately a high order framework in which to then master the skill in more detail. That last part is unique to humans and it requires probably prefrontal cortex to be much more elaborated than in other creatures. So, it's still using the mirror system but it's using it as part of the team, as it were, rather than being the guy who's doing all the work all by himself.

**GC:** Do you think that might be related to – you said, for example, that Kanzi is sort of stuck at two-year-old and can't really make it to the three-year-old stage of communication. It seems like in small children you can't stop them from imitating and that's something that just really takes off. Do you think that there's a relationship between those things?

**MA:** I think there is. Yes. So, that you've got, as it were, new mechanisms, but that evolution had – the nice thing about mirror neurons is they give you a new insight and it's such a powerful insight you'd like it to do all the work for you. But once you step back from it you realize how many different things had to come together. So, for example, all young creatures—or at least lots of young creatures—play. So that in human children we see this new capacity for imitation linked to the way they play, so that in fact that imitation is not just a sort of passive thing to be exercised in special circumstances, but allows the child to come to grips with the complexities of his culture.

And yet another evolution is that we have evolved to be good caregivers. Tomasello, who is a guy in Germany—originally American—who studies both child development and the behavior of apes, likes to show a couple of videos. One is of an ape mother—a chimpanzee mother—and her child. And basically the ape mother is just sitting there eating and the child comes and grabs her hand, and the mother kindly lets the child take some of the food but does nothing to instruct the child in how to use the food or anything else. And then the other video is a typical American mother and child sitting at the breakfast table and this totally different interaction in which the child is excitedly showing things to the mother and the mother is explaining things to the child.

And so, you see that it's sort of what you might call a virtuous circle. You get a change in part of the brain—the mirror system—but it's a virtuous circle with changes in other parts of the brain that give the overall brain capabilities that would not otherwise be there. And then at the same time as the brains are changing this means that new social structures can emerge in the group of humans, or early humans, or proto-humans, and those new social arrangements make further changes in the brain beneficial, because now there is a social structure that can exploit it. So, you've got all these different loops: loops within the brain which support evolutionary change in the brain structure, loops within society that change social groupings, but then as we say, the changes in social

groupings will make new brain changes adaptively beneficial, and so the culture shapes the biology but now the brain has changed, the culture can do things it could not do before.

And it goes back to what we were saying before about the 30,000 papers at the Society for Neuroscience meeting. That once you get to this stage you're totally overwhelmed and, again, you've got to go back to multidisciplinary teams. You need somebody who can go to Africa and really see what the apes can do. And probably the chimp expert and the gorilla expert may themselves know different things. You've got to have somebody in different societies looking at how kids learn and seeing to what extent there are general patterns in child development vs. ways in which the culture does change. One person might be really focusing on the kid playing with toys, another person might really be expert on language, and so on, and so on, and so on.

**GC:** So, I want to focus a little bit on how your hypothesis differs from other major hypotheses about language evolution, besides the idea of it involving the part of the brain involved with grasping rather than, say, like sound production, and this role of imitation. Correct me if that's inaccurate. But what else is really different about your hypothesis?

**MA:** OK. Well, if I may I'll just go back to the sound vs. grasp thing. So, there the observation is that if you look at monkeys, they vocalize. So, they'll have alarm calls. Probably most of our listeners have heard about the vervet monkeys that have a different call depending on whether one of them sees an eagle, or a snake, or a leopard. And when the monkey makes its distinctive call the other monkeys will both spread the call and react in a way that's appropriate to escaping that particular predator.

And similarly there's a husband-wife couple in Pennsylvania—Cheney and Seyfarth—who've done a lot of study of first those monkeys and now baboon

societies in Botswana, and they see both the calls these monkeys have and the way they reflect even social structures. So that there are things that one baboon might say to a subordinate but not to a superior baboon. And so, they say look at this combination: you've got a set of graded vocalizations, you've got a social structure with which it's intertwined, so this seems to really set the stage for language. And so, that I would say is the strongest counterpoint to this gestural basis for language.

The argument for gesture goes like this: that if we look at monkeys we find there's very little in the way of what you might call socially determined vocalizations. In other words, the genetics of the monkey are such that the set of vocalizations is pretty much fixed by birth. The learning is more just under what circumstances do you use it. So, the eagle call you learn as a young monkey to use for eagles and not for other birds flying overhead, for example. Whereas if you look at apes you'll see that they will use gesture. And as you go from one group of chimpanzees to another you'll find that many of the gestures are different. So, that seems to suggest that the gestures are not just genetically fixed, but are in fact responsive to something about the particular experience of that community. That's by no means the full argument, but that's the beginning of sketching for you the sort of considerations that on the one hand lend power to the counter-hypothesis—start with the voice—and yet begin to accumulate other data from the study of non-human primates that allow one to begin to make a case that if we look across the primates it may be that the gestural system is the one with the greater flexibility and thus is the candidate for winning in our story.

But in the end you have to come back to the fact that we speak more than we sign, if we do have a vocal apparatus. And so, you can then get the argument from the other end as, well why do we use the voice if we evolved to use gesture. And of course we could spend the whole episode on just that. But that's probably enough to just settle that particular idea, not by saying I've got the truth but

rather I've given you a sample of arguments and counter-arguments of the kind where we can elaborate at great length.

The biggest controversy, I suppose, is between people who want to talk about language as having a very strong cultural component vs. those who want to think about language as having a very strong genetic component. The greatest linguist of the last century—or at least the second half of the last century—was Noam Chomsky, who is still alive and well in Cambridge, Massachusetts, I believe. But he started studying language in a very interesting way, which was to say that if we wanted to understand language, just as we saw with the brain, you can study so many different things, so with language you can study so many different things. You can look at people's accents, you can worry about how sounds are produced, you can worry about how words change through history, you can think about meaning, you can look at grammar.

And he basically said let's step back and just look at the grammar: forget what words mean, forget about people communicating with each other, let's just look at the structure of language. How is it that nouns, and verbs, and adjectives get put together purely as a formal system? And he came up with some very elegant mathematical frameworks within which to think about how you could produce sentences, not by saying the words that express some meaning you had or some desire you had, but just by seeing how these formal structures he came up with—these formal grammars—could generate meaning.

And then he carried this back into the heart of linguistics and said let's look at different languages by seeing to what extent they share properties of their formal grammar. And so, he developed a set of tools which led to a discipline in linguistics, called generative grammar, for trying to see different languages in different ways. So, for example, in our language we use prepositions. We put a word like 'in' or 'to' in front of the noun it's about. In Japanese they use post-positions. They'll put a word like that after the noun. And so, you could see that

two languages would be doing almost the same thing but you'd flip a parameter: in this case do I put the preposition in front or the post-position behind. In German they tend to put the verb at the end of the sentence, we tend to put it in the middle in English, and so on.

So, there emerged from this a very nice descriptive framework that says, OK, if you got into the details of what all the words are in a language you'd be overwhelmed, but if you just step back and look at the formal grammatical structure you could build a bigger and bigger list of principles where you can see a parameter that will flip you from how that principle relates to one language to the way it relates to another language. And all that is fine. It's a very rich descriptive framework for focusing on the grammatical structure of language. So, I'm with Chomsky all the way till there.

But now he does a very strange thing. He flips from that this is a description of all the world's languages to saying, 'Oh, and it must be in the child's head at birth, and the process of language acquisition is just simply to listen to a few sentences that mummy says and basically say, oh, principle 37, I'll use parameter setting C.' And so, the idea is that what makes language learning tractable to the child is that it has this universal grammar which has all these principles and the possible parameter settings that's part of the genetic heritage, and then experience just sets the setting.

**GC:** That would be at the extreme end of the 'language comes genetically built-in' scale of –

**MA:** Right. I hope I've done a good job of presenting it as plausibly as possible, though I find it hard to present it without parody because it seems to me so strange.

**GC:** Well, I've been guilty of being harsher about it on a past episode. So, don't worry.

**MA:** But the important thing is that it has credibility because Chomsky is such an important linguist. He has also been, of course, a very powerful polemicist politically, which gives him a lot more publicity. But if we forget all that, still within linguistics he has been the dominant figure and so a lot of people who have turned to him for the tools of analyzing grammar then blindly follow him into the idea of what is the biology of language or what is the development of language, when in fact that's an area where he has not got any real experience to build on.

[music]

**MA:** The issue then is how does he support his claim. Well, it turns out there are no data that support his claim. That's probably too strong. Of course there are always some data that support something. But basically the people I talk to in language acquisition are not convinced. His argument goes something like this. He talks about the poverty of the stimulus. He says that if you look at young kids acquiring language there is very little they get in the way of explicit correction of their grammar, and when their grammar is corrected it'll often be ignored by the child. And so, he says there's a poverty of the stimulus and therefore, since children do in the first few years acquire the ability to use a language, since there's not enough stimulation to sort out the grammar there must be this innate genetic universal grammar.

So, my parody of that is that if you look at today's children and you see them surfing the web and playing video games when their parents don't have a clue, you'd have to say there's a poverty of the stimulus for web surfing. And so, it would have to be a gene for web surfing that makes it possible for kids to learn it so easily. The absurdity of that last argument, I think, reflects back to the other.

**GC:** If anything is innate it's our ability to learn.

**MA:** Yes, but ability to learn isn't enough, right? We already talked about our friend, Kanzi, the bonobo, who can learn at the level of a two-year-old but can't get up to the level of a three-year-old. So, we're back to saying, yes, the challenge is to understand how the brain changes. One of the things that I've been looking at is to put much more emphasis on this imitation: the idea that in some sense building a large vocabulary is imitation at a basic level. You see something, you hear a funny string of noises, or you see a novel gestural sign if you're deaf, and you're able as a young child, once you've hit around two or so, to rapidly—you know, tens of these things a day—to learn to imitate these novel performances, putting sounds together to make a word, putting gestures together to make a word, and associate them with a particular event, or object, or episode. So that the notion is that the building up of a brain that can do better and better imitation was one of the things that was crucial to the ability to have language.

But, going back to our earlier discussion of the fact that you have to have so many different things come together, we can speak, and so even though I talk about a gestural origin theory of the evolution of language we still have to explain why it is that we can speak in ways that apes can't. No matter how hard you try to train an ape to vocalize it just doesn't have the vocal control of larynx, and lips, and tongue, and so on, to be able to put sounds together, which is why people used things like lexigrams and hand signs to try and see how far they could go in teaching apes language. So, somehow there has to be this, again, co-evolution of increasing complexity to learn, increasing ability to imitate, better and better control of the hands and of the vocal apparatus to be able to rapidly use this system, not just for whatever you were using it for in your distant ancestors but to use it as a communication medium.

**GC:** So, what do you think is the most important unanswered question in this area? I mean, for example, I don't think it's possible at this point to know

whether the first humans were language-ready and using proto-languages and proto-signs or actually used real language. I mean that's an unknowable thing. From my standpoint I don't see that as an important question, but I would assume some researchers think that's really important. What do you think is the important question that's unanswered?

**MA:** Perhaps I'll turn it around.

**GC:** OK.

**MA:** I mean there are so many things that I think are important and haven't been answered. So, let me just say some things that don't answer your question, and then you can zoom in and ask me again and maybe I'll be more helpful. There's an interesting slogan now in biology called evo-devo, which says you need to study evolution and development together. Of course, evolution is a very complex theory nowadays based on a huge number of studies all the way from molecule to species. But if we take it as simplest, the idea of evolution is that you have a certain gene structure and you then grow to an adult, and if you have lots of kids then that gene structure is more likely to be replicated, and so the strong selection through reproductive success on different types of genetic structure.

But what do the genes do? The genes are there all the time and they're being expressed in different ways in different cells to guide the way cells are formed, the way cells connect, the way cells learn, and so on. So that evolution may look as if it's selecting adults but in a way it's more directly linked to genes, which are more directly related to the development of the creature. In other words, genes are both controlling how you develop and then how you act and interact with the world when you've developed. So that in fact evolution is selecting both: what are the genes that help you develop and what are the genes that help you succeed once you've developed.

So, evo-devo goes back and says let's focus on the development part. It ties a little bit to what we were saying before. We went from language to how does the child get language, and we saw that in some sense my sticking point with Chomsky is not an argument about the evolution or origins of language but it comes down to what evolved in the brain and the idea of a totally different notion of how the child develops. In one case he's already got a library of grammatical structure etched in the genome, according to Chomsky, and that guides the way he develops vs. this much more learning-oriented view while still looking for what's special about humans.

I think that notion of developing the story in more of an evo-devo framework which requires us to understand what is the developmental pathway in modern humans for language, how does that differ from the developmental pathway for communication in other primates, and then eventually to understand the genetic basis for that. In terms of doing science the problem is that there are no fossils of the brain and there are no fossils of language. All the videotapes of 20 million years ago have degraded by now. But it's sort of a mythical story. So, what makes it science?

Well, what makes it science is going to be that we do comparative primatology, and more generally with other species. So, we will look at better and better understanding of what goes on in the brain as we look at language—that's neurolinguistics—and then what is it that is in common? So, I say we do have a mirror system, let's look in more detail at that mirror system that underlies our manual skill behavior and the mirror system that underlies but is part of a bigger system for our language behavior.

Now let's compare that to what we can get from chimps. Well, with chimps we can't do detailed neurophysiology but we're increasingly going to be able to do painless brain imaging on chimps that doesn't traumatize them. And so, we will have more understanding at the same sort of level we have with humans of how

the brain lights up in different ways for a range of behaviors where chimps come closer to human language behavior or further from language behavior.

With the monkey we have the advantage that we can record from individual neurons—that's how the mirror neurons were discovered—and get much more insight into circuitry. So, in a sense the evolutionary story is a fascinating intellectual framework for doing science, but the actual science is going to be, I think, in terms of getting deeper and deeper into the comparative neurobiology of primate brains to understand how it is that apes use their mirror neurons, how the monkeys use their mirror neurons, how we use our mirror neurons, and come to understand our brains better and better.

And meanwhile there's this whole other area of complexity we haven't really gotten into. And that is that now we do have the ability to study DNA and there are going to be lots of people trying to patch the changes in the genome onto the changes in their expression in neural circuitry and in behavior. So that as we come up with better and better analyses of the brains of different creatures and begin to understand how those changes are correlated with changes in the genome we finally may get to the point where we can say, 'Look, here is the difference in the genes that control the human neurosystem and the genes that control the monkey neurosystem, and, look, these relate to the genes that relate to motor control for the hands and this is the way it controls the motor control of the vocal cords,' and so on, and so on. So, in the end there will be this even more hideously complicated set of data which will allow people maybe 50 years from now to step back and actually state as pretty much scientific certitudes the things that are now based on scanty data but allow us to at least make fruitful and challenging hypotheses that can constrain the scientific work that will lead to those very strong insights down the line from now.

**GC:** So, we can't ever really know for sure what happened in the past, but by doing this comparative work we may be able to test the hypotheses about what's

different between us and the other primates. And that would come down to answering some of the questions about –

**MA:** Yes, I think in the end we will be able to, by doing the comparative study, by having fossil records not of what the brain was doing but of what are the cultural artifacts, what are the hunting artifacts, and so on, of early people, we'll begin to make more plausible connections. So, in the end we will, I think, have a transition from where theory is something we say, 'We've got to test, we've got to test,' to, 'OK, this looks correct. Let's move on to other questions because we've reached consensus.'

**GC:** Well, I want to thank you again for coming on. And there were some details we didn't have time to get into today. I especially enjoyed the paper that you sent to me about the new sign languages. I thought that was one that I would have liked to have talked about, but I don't want to take up any more of your time. I'll link to that in my Show Notes for my listeners. Is there anything else you would like to share before we close?

**MA:** I think just to reiterate the point that has come up again and again in our conversation about how exciting it is to have questions of this kind which allow one to interact with brilliant people doing so many different things: from people studying sign languages, to people off in the African jungle, to people at the workbench trying to understand genetic control, to people studying the brains of monkeys, to people coming up with ingenious experiments on human brain imaging, to people looking at the development of children—some children who are deaf, some who are not—looking at children learning how to play, looking at children learning how to use language. That really is, I think, the excitement of science. But as we've also discussed it's also the challenge for the young scientist is how do you within such an exciting matrix find your own role which allows you to become specialist enough to really get hard useful results, and yet at the same time become fluent enough in a range of languages of different disciplines so that

you can take your insights and share them with a community of people doing so many very different things.

**GC:** For me, trying to share these ideas with a more general audience, that's a challenge also. But one great thing is I know that I'm never going to run out of material.

**MA:** That's true. And I really appreciate your efforts. I think it is so easy to get into exciting conversations with a few specialists and the challenge of sharing that with so many people out there who want to know and understand is very important. So, I thank you for your work.

**GC:** Well, thank you. And I hope you will keep me posted if you put out something that I can use. Just send me a link. And I'll try – it's really hard – that's one reason why I generally concentrate on books that people write for the general audiences. That's kind of my little niche usually. But I did Rizzolatti's—and I realized on my podcast I totally mispronounced his first name—I did his book on mirror neurons and I realized that I wanted to get more into this. That gave me an excuse to interview you, because I've been aware of your work but couldn't figure out an excuse for calling you.

**MA:** Excellent. Well, now I'm motivated to write a book for the general public so we can talk again.

**GC:** Oh, great! Well, thanks a lot. I will send you the links when the show comes out so that you can hopefully share it with others.

**MA:** Terrific. Good to talk to you.

**GC:** You, too. Thanks a lot.

**MA:** All the best. Bye bye.

**GC:** OK. Bye.

[music]

I enjoyed very much talking with Dr. Arbib, and thankfully I did have a normal voice on the day that he was interviewed. Hopefully my normal voice will be back by the time I record the next episode of the *Brain Science Podcast*.

I just want to remind you, especially if you're a new listener, that if you aren't subscribed to the *Brain Science Podcast* the easiest thing to do is to go to the website at [brainsciencepodcast.com](http://brainsciencepodcast.com) where you will see information about all the different possible ways of subscribing. Of course it's easily available through iTunes. I also want to remind everyone that I would love to hear from you. Either email me at [docartemis@gmail.com](mailto:docartemis@gmail.com), or come by the Discussion Forum at [brainscienceforum.com](http://brainscienceforum.com). I've now had the forum up for almost a year, and it's still pretty small but I think it's growing, and I'd love for more of you to come by and start and participate in discussions there.

In a couple of weeks we will be having the next episode, which will be our semi-annual review episode where we will look back on the past six months and also talk about the upcoming episodes which will include several more outstanding interviews. Also, don't forget to listen to my other podcast *Books and Ideas*, which is at [booksandideas.com](http://booksandideas.com).

I appreciate your listening and I look forward to talking to you again in a couple of weeks.

[music]

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