Praise for *The Birth Of The Mind*

….a wonderful contribution to our understanding of the biological basis for higher mental processes. It unravels dilemmas, perplexities, and confusions, and carries the reader to the edge of current knowledge in areas of great fascination and promise.”

Noam Chomsky

Brilliantly original … a contribution both to popularizing science and to science itself.

Steven Pinker

Without a doubt the clearest account of the relationship between genes and the environment that I have ever read..

Derek Bickerton
Author of *Language and Human Behavior*

Engaging and clear…covers a truly amazing range.

Richard C. Atkinson
Past President of the University of California

Fast, accurate, and informative – an excellent overview of new ideas and research [that] will light up all eight of your brain’s lobes

Greg Bear
Author of *Darwin’s Children*

Marcus’ upbeat, friendly writing style…makes even the most arcane genetic principles a joy to read.

*Publisher’s Weekly*

Describes the complex world of genes in an entertaining and gripping way … dispelling the myths that impede the way we think about genes and their role in making brains, and hence minds.

*Nature*

Einstein famously advised that everything should be made as simple as possible, but no simpler. Marcus takes this to heart.

*Nature Neuroscience*

Totally mind-boggling…a page-turner that is all nonfiction.

*Curled Up with a Good Book*
NYU psychologist Marcus strikes a rare and delicate balance of scientific detail and layperson accessibility in this overview of an exploding field of inquiry. He traces a compelling story through the classic genetics and brain experiments of the past century up to present-day research, intriguingly illustrating how the human genome is intertwined with brain development, showing how the mechanisms that build brains are extensions of the mechanisms that build the body. Marcus dispels popular misconceptions of genes, showing, for instance, that most behaviors and disorders are much more complicated than headlines such as "gene for obesity discovered" would have us believe. Heavy explanations of complex results and abstract concepts are leavened by Marcus' upbeat, friendly writing style, which makes even the most arcane genetics principles a joy to read. Experiments with vision and language are particularly well-represented, with vivid descriptions adding color to the technical prose. If there is a fault here, it is that the book jumps around a bit too much, attempting to collect several decades of research and many threads of thought into a single slim volume. A lengthy glossary and bibliography, along with meticulous footnoting throughout, are helpful for those wishing to educate themselves further on the subject, but Marcus gives most readers more than enough to think about here.

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such as Bacon enthusiastically adopted the artisanal epistemology, so that as Smith aptly notes, it was the artisan’s practical power to generate novel effects from nature, rather than the tricky technicalities of Copernican theory, that made the scientific revolution exciting to many contemporaries.

The Body of the Artisan is a fascinating and significant contribution to a more social, collective, and diversified history of scientific (and artistic) transformations in early modern Europe. The account of artisanal epistemology is convincing and innovates through its focus on painters, sculptors, and engravers. However this makes the term “artisan” slightly misleading. Although Smith is at pains to avoid the anachronistic term “artist,” her choice of artisans with whom to represent artisanal epistemology falls mostly on an elite of decorative and fine artists. Absent are many of those traditionally discussed in works on science and artisanry.

HUMAN COGNITION

Dispelling Rumors of a Gene Shortage

H. Clark Barrett

To judge from some recent discussions about evolution, genes, and the mind, a mother could be concerned that her child, born with only about 30,000 genes, might have serious developmental problems or at least be unlikely to follow a typical human developmental pathway. Experts have made much of the claim that 30,000 genes aren’t nearly enough to specify the vast number of connections in the brain (the “gene shortage”) (1). Our genetic endowment might not even be sufficient to make us reliably human because, according to some, genes cannot specify particular developmental outcomes (2, 3). One could get the impression that all the genome can do, because of its limited information capacity, is to specify the basic properties that allow the brain to be an “organ of plasticity” (4). Humans must be human, on this view, because some parameter, like degree of plasticity or number of neurons, has been tweaked. Moreover, there has “not been enough time” for many new psychological capacities to have evolved via changes in the genome since the divergence of the human and chimpanzee lineages (5). Such arguments have been widely invoked to downplay the role of evolution in shaping the human mind as we observe it today. They have also been used to argue against the view, associated with the growing field of evolutionary psychology, that the many specialized psychological abilities of humans are due to natural selection specifically for those abilities.

For our hypothetical mother, this might be worrying news indeed. Her child might just as easily turn out to have the brain of a chimpanzee. The worried parent will find such fears assuaged by Gary Marcus’s new book, The Birth of the Mind. With clarity and precision, Marcus, a developmental psychologist at New York University, lays to rest the rumors of a gene shortage and also rebuts the argument that minds are too complex to have been designed over evolutionary time by the process of natural selection. He shows instead that minds are built over the course of individual development by genetically regulated processes that have been molded by natural selection to build brains that are functionally organized in ways that promoted human survival and reproduction in the evolutionary past.

Marcus begins by observing that the brain is far from the only place in the body where our small genome gives rise to complex, functionally organized structures; the...
liver or the heart, he notes, might just as easily suffer from a gene shortage. He surveys the state of our understanding of genes. Rather than static pictures or blueprints of phenotypes, genes are active “agents” that interact in precisely orchestrated ways to build organisms.

The author shows us how this view allows us to understand the fantastically complex, yet fantastically well-coordinated, generation of the mind. In cognitive science, it has long been customary to think of the brain as a computer. Marcus shows that the developmental system that builds the brain can also be thought of as an algorithmic system, one that operates through frequent interactions with its internal and external environments. He likens the genome to a compressed file, and the cellular machinery with which it interacts to a decompressor. However, this developmental system is full of ingenious devices not typically found in silicon-based computers, including gradients and switches that allow its operations to be context-sensitive, feedback loops, and self-generated “test patterns” that allow the system to tune itself. Such phenomena challenge our standard notions of flexibility and plasticity as being fundamentally at odds with genetic control. It is precisely because of genetically specified developmental procedures that the brain is able to achieve its astounding plasticity. Plasticity is not simply responsiveness to change (as when a basketball responds to being punctured) but responsiveness that produces the correct outcome in diverse circumstances. As Marcus makes clear, although we are vastly more complex than desktop computers and therefore have potentially many more ways of breaking, the fact that our developmental process is relatively far less prone to crashing while booting up from the zygote has everything to do with natural selection for specific developmental outcomes.

Perhaps most important, Marcus tackles a question fundamental to current debates about the mind: How could so few genes account for the large array of humans’ specialized psychological skills? Here, arguments have focused on the idea of modularity, the notion that specific skills are handled by specific areas or circuits in the brain. Evolutionary psychologists have argued, following William James’s insight over a century ago, that the flexibility and power of human intelligence result from natural selection having added, not removed, specialized machinery to our minds. However, many have intuited that there could not be very many modules because of the gene shortage, a lack of evolutionary time, or both. Clearly, the blueprint idea of a one-to-one-mapping between genes and modules (in which an entirely new suite of genes is required for every new module) seems to lead inevitably to a gene shortage. But Marcus shows that our knowledge of developmental genetics debunk this simplistic view. He discusses ways in which a complex regulatory system can build distinct units without an entirely new set of instructions for each. For example, an animal with 60 legs would not necessarily need 10 times as many genes as a six-legged animal, and although human arms and legs differ considerably, we do not require an entirely distinct set of genes for each type of limb. The same considerations apply to the components of the brain. Marcus points to many ways in which evolution can generate features of organisms’ phenotypes that are modular in design without an equivalently modular genome. He also mentions interesting mechanisms for the generation of novel structures—such as duplication of genes within the genome, which allows modification of the copy without loss of function of the original—that could provide useful insights for those seeking to understand the origin of novel psychological capacities in humans.

The account Marcus offers will be refreshing to those who are tired of simpleminded debates about the role of genes and evolution in shaping the human mind. If there is a drawback to the book, it is that the author doesn’t show us exactly how a tiny number of genes builds such a complex brain, only that they can. But he is hardly to blame for this, given that we have a long way to go before we have a complete understanding of brain development. The strengths of The Birth of the Mind lie in its sophisticated exposition of how genes guide development and its convincing argument that we need not hold out hope for some magical, as yet undiscovered, process to account for the brain’s complexity. Plain old natural processes, about which we know much already, will do.

References


In The Quantum Universe (1987), the authors offered an accessible, nonmathematical introduction to the physics and applications of quantum theory (especially the wave nature of particles and the Pauli exclusion principle). In this updated edition, again copiously illustrated, they have added accounts of quantum paradoxes, Schrödinger’s cat, and the Bell inequality. They also discuss nanotechnology and quantum mechanics in computing, cryptography, teleportation, and science fiction.
A recipe for the mind

**The Birth of the Mind: How a Tiny Number of Genes Creates the Complexities of Human Thought**
by Gary Marcus


Anthony P. Monaco

If the mind can be explained from the workings of the brain, and the brain develops by direction from our genes, then presumably the mind can be explained from our genetic make-up. But how can only 30,000 genes make a brain with billions of neurons and encode the particular aspects of cognition that make us human?

The Birth of the Mind tries to unravel this complex problem by first explaining what we know about each component of the argument: the mind, the brain, our genes and the environment. The breadth of examples used to achieve this is impressive, encompassing 40 different organisms (from bacteria to chimpanzees), 30 different genes and 20 different brain regions.

The author, Gary Marcus, spends much of his efforts building up the reader's knowledge base. It is difficult to make an argument that involves such diverse disciplines as evolution, genetics, gene expression, cell biology, neurobiology and psychology without teaching the reader the bare essentials. Marcus does particularly well to make the relevant issues in these areas understandable to the lay reader, and does an even better job of dispelling the myths that impede the way we think about genes and their role in making brains and hence minds.

Marcus is a cognitive psychologist who understands genes. He has researched his topic well and describes the complex world of genes in an entertaining and gripping way. He dispels the myth that there are too few genes by explaining that single genes can encode several proteins with different functions, and more importantly that genes can be turned on and off in groups in multiple combinations to perform highly orchestrated and complex functions. He discards the analogy of genes as blueprints for building a brain (or any other organ in the body), and prefers to think of genes as the 'recipe' required for the correct development of the brain. He explains heritability and the difference between single-gene effects — and their resulting monogenic and relatively rare diseases — and complex genetic interactions, which cause more common diseases.

He also unravels the paradox of flexibility. How does the brain of a newborn, with its complex structures and connections, have the plasticity to enable it to respond to environmental influences as it develops further? Marcus disentangles the nature-versus-nurture argument using many examples from neuroscience research that show that the brain is built by genes in a self-organized way before being reorganized and shaped by experience and the environment. It is not a battle where one side wins, but a vital interaction.

Having clarified these two paradoxes using our current knowledge of genetics and neuroscience, can we explain how genes make minds? The story is only beginning. This book shows that genes build brains and that brains are designed to be flexible and to learn, but the jump from genes to the mind is an indirect one. The question cannot yet be answered, and it is not entirely clear where the answer will come from.

Will geneticists pinpoint genes and gene pathways that will inform us about human cognition? This is already happening but will provide only part of the answer and confirm that genes are directly influencing mental abilities. Will cognitive scientists detail the relationship between neural structures and mental structures? This area of research is expanding, thanks to modern brain-imaging techniques that enable researchers to ‘see’ the brain in action. The path ahead to integrate these disciplines to gain a fuller understanding is optimistically vague, and anyone interested in the topic would be encouraged to read this book.

Lay readers may be daunted by the sheer complexity of the science — even with the best intentions of explanations in lay terms, a glossary and an appendix to explain the genes. But the more scientifically minded, especially those with a background in either genetics or neuroscience, would gain much from the book. It would at least dispel some myths and paradoxes, leaving the possibilities open for an eventual understanding of how 30,000 genes can provide the recipe for the mind.

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Building brains from genes

The Birth of the Mind: How a Tiny Number of Genes Creates the Complexities of Human Thought
by Gary Marcus
Basic Books, 2004
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Reviewed by Charles Jennings

About half of the estimated 30,000-odd genes in the human genome are expressed in the brain. Among these genes is hidden the explanation for our unique human cognitive abilities, and for many of the differences between individual people. Developmental neurobiology is the essential bridge for connecting genome to behavior, but despite its obvious importance, there has not yet been a popular book devoted to this subject.

The Birth of the Mind is an ambitious attempt to fill this gap. The author, Gary Marcus, is a cognitive scientist, but he has learned a lot about developmental neurobiology and has written a concise and very readable introduction to the field. By drawing on related disciplines such as genetics, cognitive science and evolution, he provides an overview of how the interaction between genome and environment gives rise to the human brain—and by extension the human mind.

Marcus gives as clear an account as I have ever seen of the nature versus nurture ‘debate’. In fact, most biologists no longer regard this as a debate (genes and environment are both important), and the fact that it is still perceived as such by the public may reflect the lack of clear popular account, which this book now provides. The concepts of pleiotropy, heritability and the interaction between genes and environment are also clearly explained. The popular press loves to announce the discovery of ‘genes for’ everything from adultery to zoophilia, and this will probably continue as long as there is a demand for light scientific entertainment; anyone who reads this book, however, will understand why this is a misrepresentation of what genes actually do.

I found the discussion of innate behaviors particularly insightful. These are often described as ‘hardwired’, the implication being that they are inflexibly determined by the genome. But as Marcus emphasizes, there is a distinction between ‘hardwired’ and ‘prewired’. Just as computer software often comes with default settings that can be customized by the user, so the brain develops with prewired patterns that can be modified by later experience. The failure to distinguish these two situations has led to endless confusion in the debate between nativism (the belief that cognitive abilities are prewired) and empiricism (the opposite), and Marcus does a nice job of recasting the discussion in a more constructive way.

He also dispels a more recent myth, namely that there is a ‘gene shortage’ that precludes genes from encoding complex behaviors. It is admittedly surprising that we have only 30,000 genes but 100 billion neurons, particularly given that the nematode C. elegans has nearly as many genes yet only 302 neurons. But as Marcus makes clear, genes are complex individually and give rise to even greater complexity by acting in combination; moreover, the truth is that we have no basis for surprise, absent a theory to explain how many genes are needed for a given degree of biological complexity.

Einstein famously advised that everything should be made as simple as possible, but no simpler. Marcus takes this to heart, and his book contains many simplifications but few misrepresentations. Where to simplify is a matter of taste, and not everyone will agree with his decision to avoid the complexities of transcriptional and posttranscriptional regulation. He compares genes to Boolean logic gates; if a certain combination of transcription factors is present, THEN make this protein. This is a useful analogy for the general reader, but it may be a violation of Einstein’s maxim. Genes sometimes behave as analog rather than digital devices; that is, they show graded rather than on/off expression. An important issue for the emerging field of systems biology is to develop theoretical frameworks for understanding gene interaction networks, and it is not clear whether discrete models will suffice or whether more complex continuous models will be needed. But Marcus’s formulation is certainly provocative and probably not seriously misleading for his target audience.

The book is enjoyable to read. Marcus writes with a light touch (his mentor was Steven Pinker, and it shows), and if he occasionally goes too far (e.g., “without genes, learning would not exist”, p. 170), an occasional vapidity seems preferable to the ponderous academic prose by which too many scientists express themselves.

I have one reservation, however; despite the book’s title, anyone looking for philosophical insights into the mind/brain relationship will be disappointed. Marcus announces this at the outset. Referring to Francis Crick’s ‘astonishing hypothesis’ that our thoughts are determined by physical events within our brains, he says: “I can’t say that I am astonished. To many people of my generation, it has become obvious (maybe even banal) that our thoughts are the product of our brains.” I wonder whom he has been talking to. In my experience, the great majority of lay people are dualists, and some find the materialist viewpoint profoundly disconcerting. Even those of us who consider ourselves hard-nosed materialists sometimes sense the chasm that separates our scientific beliefs from our sense of self. Marcus seems untroubled by such thoughts, and his book will be of little help to those who are.

But overall, The Birth of the Mind is a fine general introduction and I have no hesitation recommending it to students, scientists from other disciplines, or lay readers wanting to learn something about this fascinating and fast-developing field.

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e-mail: c.jennings@natureny.com
The subtitle of *The Birth of the Mind* by Gary Marcus, Ph.D., tells the basic story: how a tiny number of genes creates the complexities of human thought. Once you delve into this fascinating book, you will be amazed at just how powerful those tiny number of genes really are. Powerful enough to shape our realities, and create our experiences. Powerful enough to make body parts do what they are supposed to do, and to adapt accordingly when our environment demands we do so. Powerful enough to make us think, and to drive us to behave in the ways we do as human beings.

Marcus, who is an associate professor of Psychology at NYU and an award-winning cognitive scientist, writes in a down-to-earth style about an out-of-this-world subject matter – namely, the world of the genome, and the constructive abilities of genes that literally create the brain. Using plenty of cutting-edge research as a backdrop, as well as his own studies with child development, the author leads us on a journey into the brain and into the deepest realms of the biology that shapes our mental thought processes.

Marcus first takes on the nature-versus-nurture debate, showing how the Human Genome Project is drastically altering our sense of how the brain works with the most recent discoveries of just how much our genes influence human intelligence. The author then, in language completely accessible to the lay reader and science novice, tells us what these things called genes really are, what they do, and how they come to effect the mighty brain and all its infinite abilities and complexities. Starting with research into childhood development, and covering decades of animal research up to the most current human brain studies, this awe-inspiring book shows the intricate relationship between our genes and our thinking patterns and learning styles. It also shows what is in control, and clearly, the genes win hands down.

In fact, we come to understand that our brain’s origin is genetically mapped, and that all we perceive is directly related to the genes operating like thousands of busy little computer programmers in our bodies. We learn that mental evolution is tied directly into the world of genetically programmed codes that influence how we think and how we view our world. We also learn about the amazing adaptability of the brain and body, and how our genes help us to survive in a constantly changing world. We also realize, through the remarkable research being done today, that our ability to learn and grow and experience new things is connected to our genetic makeup, but that we still have the tools to trigger greater mental capacity. Destiny may be in our genes, but we still have some say in the matter of how we use our grey matter. In fact, this book shows that the more we use our brains, the more brains we seem to have to use.

Although I did get bogged down in some of the heavy research and technical talk about the various parts of the brain and which does what, and I was occasionally put off by the emotionless descriptions of brutal animal experiments (we do some pretty awful things to other sentient beings in the name of "learning" more about ourselves), I found *The Birth of the Mind* totally mind-boggling, pardon the pun. It is a page-turner that is all nonfiction, based upon the growing body of factual evidence that points to a human brain so complex and intelligently designed, it is breathtaking.
This is a wonderful book which I heartily recommend to any interested readers who want to explore either genomics or the workings of the mind/brain. In fact, I loved this book and think that many readers will view it similarly.

Throughout the book, which is written for reasonable well-educated lay-readers, Marcus points out the misconceptions which are rife in most peoples' views of genomics and especially psychogenomics and explains how just 30,000 genes can and do encode the incredibly complex brains of human beings, with billions of neurons and trillions of neuronal connections. He makes the major point that "what is good enough for the body is good enough for the brain", and that the genes which build the body overlap with and work in the same way as the genes which build the brain, using many examples throughout the book from ocular dominance columns and other areas.

In nine short chapters he covers a great deal of ground, and the chapter titles themselves keep us reading - "Born to Learn", "Brainstorms", Aristotle's Impetus", "Copernicus' Revenge" and "Paradox Lost", among others.

He begins with a quote from Richard Dawkins: "The genetic code is not a blueprint for assembling a body from a set of bits; it is more like a recipe for baking one from a set of ingredients. If we follow a particular recipe, word for word, in a cookery book, what finally emerges from the oven is a cake. We cannot now break the cake into its component crumbs and say: this crumb corresponds to the first word in the recipe; this crumb corresponds to the second word in the recipe, etc." Genes "work" with one another, and they have major interfaces with the environment as well. Thinking and behavior are not completely determined by the genes, which are necessary but not sufficient conditions.

Marcus uses MIND rather than BRAIN in his title, but immediately cites Pinker's definition of mind as "what the brain does." He is a fan of Crick's fascinating book, The Astonishing Hypothesis, so this is not a dualistic book, and the author dismisses dualism without really considering its arguments. He extends Crick's thesis, arguing that the mind has its origin in the brain, and the brain has its origin in the genes, and he points out that consideration of genes has been very deficient even in recent work on theory of mind. At the same time, he is very careful to point out that genes do not control our destiny - they contribute importantly, as do all kinds of internal and external environmental factors.

After this introduction, Marcus turns to the question of the mind/brain of human neonates and argues about what is encoded and what is plastic. He next turns to the structure of the brain and its flexibility. He provides a wonderful description of genes and proteins and develops the concept of "genetic recipes". He argues well that the role of genes in the brain is the same as in all other organs. He moves on to the interaction of genes and the environment in brain function - an excellent and well-informed discussion. He follows with a wonderful chapter on evolution which clarifies more than anything I have read why, with 98.5% genomic similarity to chimpanzees, human beings are so different. Finally, he argues that vague concepts such as "nature and nurture" are truly on the verge of being replaced by "a synthesis of biology and the cognitive sciences".
Throughout the book, he downplays a special role for genes in the brain vs other organs, and he is very convincing. "In fact, I use the term 'mental gene' as a bit of a joke. Although many genes affect our mental life... 'mental genes' are pretty much the same as other genes: self-regulated instructions for building parts of a very complex biological structure... Many of them... are the same. From the perspective of the toolkit of biology, there is little difference between a gene expressed in the brain and a gene expressed elsewhere. A gene is a gene is a gene." And this, for Marcus, is an organizing principle. Our genes lead to our sense of self, and our sense of self realizes that it shares its genes with others throughout the animal kingdom: he (and I) find this unifying, gratifying - solace, in fact.

The chapter on evolution is the heart of the book, in some ways, and a truly outstanding discussion. Our genes add to survival value by making our brains and our selves flexible enough to adapt and care for ourselves. Marcus considers many important topics but has an especially fascinating view of the role and place of language in our evolutionary development, which is central, crucial, and certainly imperfectly understood and still very controversial. The author presents the arguments of Fodor, who believes that formal language is distinct from a "language of thought" in the brain, and Gleitman, who points out the lack of cognitive differences in people who speak different languages and argues that a pre-existing conceptual component of the brain produces what we view as language as its mental representation. (There are many opposing arguments about this issue, of course.) Marcus points out that the "genes for language" reported by the media are not unique to language, and that our "language genes" do not just come from the 1.5% of genes we do not share with chimpanzees but from the other 98.5% as well. He also makes explicit the roles of many genes in determination of mental traits and downplays the idea that we shall find one gene for depression, for example.

He provides a very brief but fascinating overview of real and potential ethical issues, especially in regard to "designer babies". Marcus provides an excellent appendix providing interested readers with a good account of methods used in genomic research - an excellent introduction to this topic. There is an outstanding glossary, seventeen pages long, defining common terms of molecular biology and genomics for the general reader. The chapter notes which follow are useful and are annotated in many cases. There are thirty pages of references which really provide a major resource for scientific and medical readers who wish to pursue the book's topics in more detail.

I cannot find any significant aspect of this book to criticize. It is well written, and the author has a sense of humor, which can be very helpful in a book like this. For example, he alludes to a "study" allegedly finding that human infants are stupid, which is a wonderful, satirical piece in The Onion. He realizes that psychogenomics is in its infancy and makes an occasional delightful comment such as, "Scientists are a lot better at 'finding' genes for complex mental traits than they are at replicating their findings." This is a superb book, and I recommend it most highly.

Lloyd A. Wells, Ph.D., M.D., Mayo Clinic, Rochester, MN
Genes’ impact can be altered

- Genetic information can lead to helpful interventions for those needing assistance to mitigate problems

BY GARY MARCUS

The human brain has been described as everything from the “last frontier” and “biology’s greatest challenge” to “the most elaborate structure in the known universe” and Woody Allen’s “second-favorite organ.”

With rapid advances in genetics, neuroscience and psychology, we will soon have a radically improved understanding of the contribution of genes to the developing brain.

Used wisely, that knowledge could lead to an entirely new approach to social intervention. But doing so will require overcoming common misconceptions about how genes operate.

Genes are widely seen as either blueprints or deterministic dictators. Neither view is correct. A single organism’s collection of genes — its genome — can lead to many different outcomes, depending on the surrounding environment.

The African butterfly Bicyclus anynana, for example, can take on two different forms — colorful in the rainy season and dull brown in the dry season — depending on how its genes are switched on and off.

The consequences of the responsiveness of genes to the environment may be even more profound in a human. A butterfly’s coloration pattern may only be skin deep, but the switching of human genes in response to the environment may profoundly shape our personalities.

Contrary to our usual belief that genes force us toward one possibility rather than another, biology is revealing a different picture in which genes arm us with ways of responding to different environments.

One example: A recent study — still preliminary, but breathtaking in what it might mean — suggests that people who bear a particular version of an enzyme known as MAO-A are predisposed to violence, but only if raised in abusive environments.

This particular version of...
The Need for Cooperation Is in the Genes

St. Francis is said to have called all creatures, no matter how small, brother and sister because he knew they had the same source as himself. Fifty years ago, science identified its version of that source: DNA, the double-stranded molecule of life. Apart from a few viruses, every creature, great and small, owes its very existence to the DNA molecule. Consequently, analysis of DNA promises to hold the key to unlocking how and why humans differ from other animals.

With the announcement in early December that the chimpanzee genome had been sequenced, it may seem like answers are at last just around the corner. It is not hard to imagine some cosmic version of the children's game "spot the difference," in which a simple inventory of the differences between the chimp genome and the human genome will tell us all we need to know about what makes humans special. But in reality, the two genomes, chimp and human, are simply long lists of "letters" (DNA nucleotides), and knowing how these letters differ doesn't tell us what those differences mean.

In some ways, scientists are more puzzled than ever; as recently as a few years ago, most assumed that the complexity of human nature would be mirrored in the complexity of the genome. Nobody anticipated that the human genome would have scarcely more genes than that of a chimpanzee, or that 80% of the genes in a mouse would have some counterpart in a human. It is now clear that radically different species can have startlingly similar DNA.

In hindsight, the great genomic similarities that are emerging should not be so surprising. Genes are, first and foremost, about building the ingredients of life, and all living organisms are made up of the same basic chemical elements and dependent on some of the same basic metabolic and cellular structures. To say that two creatures have similar genes is a bit like saying a bagel and a croissant have similar ingredients; the real trick is understanding how those ingredients are combined.

This much is already known: Whereas sugar and flour passively depend on a baker, genes take a far more active role in the body's self-assembly. Every gene contains both a template for building a particular protein (such as collagen or hemoglobin) and instructions for regulating when and where that
protein will be built. And initial results suggest that it is in the latter, "regulatory" portion that the biggest differences among species lie.

Although the protein template portions of our gene sequences differ on average by less than 2% from those of chimpanzees, the regulatory regions may differ by as much as 12%. As we come to better understand how those all-important regulatory regions work, we will have an entirely new way in which to understand what makes humans unique, and how that uniqueness relates to the vast library of genetic material we share with other creatures.

But this is not a problem for genomics alone; the spectacular gene "sequencing" machines that identify DNA nucleotides by the billions are still just transliterators, devices that read letters. To fulfill the promise implied in the newly sequenced chimp genome, universities -- and society at large -- will need to increase support for something that they have long given lip service to: interdisciplinary research. For puzzling out what makes humans special is not just about spotting the differences but understanding what those differences mean.

To make the most of our growing knowledge of how genomes vary between species, biologists need the help of many others. To assess the influence of a given gene on the brain, for example, will require cooperation among neuroscientists who can assess how that gene influences the development and function of the brain, psychologists who can assess the influence on behavior, linguists who can speak to the question of language and anthropologists who can speak to the question of culture.

The sheer rate of research makes it impossible for any single scientist to know everything about his or her own field, so it is essential that society support the rare researchers who try to work beyond the boundaries of their own disciplines. Universities reward psychologists for being good psychologists and biologists for being good biologists but stint on supporting biologists who delve into psychology or psychologists who stray too far into biology.

It may take Congress to change that way of thinking, to shake up the staid ways of the academy, but in the end only an increased fostering of interdisciplinary research will allow us to truly understand what makes us uniquely human.

*Gary Marcus, associate professor of psychology at New York University, is author of "The Birth of the Mind: How a Tiny Number of Genes Creates the Complexity of Human Thought" (Basic Books, 2004).*
Behold the Talking Chimp
Zeroing in on the genetic basis of language

By Gary Marcus

From our common ancestor with chimpanzees, it took only six million years, give or take, to develop the ability to speak. And, as we now know, the vast majority of our genetic material has been altered since that time. Language, and whatever else separates us from chimpanzees, has its origins in alterations to no more than about 1.5% of the genome, a pretty neat trick, when you consider how handy talking can be.

How did evolution pull it off? Some important clues have already come in, such as a recent study showing that there has been an important change in a gene relating to jaw structure that may have opened the way to the rapid expansion of the human brain, which is about four times the size of a chimp's. But size isn't everything. While a human-sized brain might be a necessary prerequisite for language, it is hardly likely to be sufficient. Although whales and elephants have significantly larger brains than ours, they don't have anything as complex as human language. Only with further evolutionary changes to our brains, perhaps in the last 100,000 years, did our ancestors begin to talk.

At the moment, the most obvious indicator for optimism is the fact that in the last 100,000 years, a fairly small number of alterations to no more than about 1.5% of the genome, a pretty neat trick, when you consider how handy talking can be.

Although it is too early to tell for sure what we will discover, my research into the interface between language, genetics, and neurosciences leads me to predict that the nature of the genetic changes that contributed to the evolution of language will still converge on two fundamental truths:

1. **The Pattern of Patter:** First, the biggest difference between us and the other great apes is the ability to represent what linguists call hierarchical structure, small units coming together to form a noun phrase; a verb (loves) and the noun phrase coming together to form a noun phrase (loves the girl); another noun phrase combining with the verb phrase to form a sentence (The sailor loves the girl); and that sentence combining with other bits to form still further sentences (Mr. Lynch knows that the sailor loves the girl).

2. **The Source of the Source:** Second, although human language is qualitatively different from any other communication system found on the planet, I suspect that we will discover that the neural circuits that underlie language, to a remarkably large extent, built out of preexisting parts. The French Nobel laureate François Jacob once described evolution as a tinkerer, who makes use of whatever available bits and pieces might already be around. This is obviously true when one considers, say, the wing of a bird, the flipper of a dolphin, and the arm of a human being: Adaptations are often variations on a theme. My prediction is that we will come to understand the neural and cognitive basis of language, we will see that the nervous system that consolidated of reusing preexisting parts applies in mental systems.

For example, Broca's Area, a region of the brain that is specialized for language, has developed to play an essential role in language, may have evolved from neural areas in ancestral species that were used for temporal sequencing or motor control.6 Similarly, FOXP2, the human gene that is almost certainly thought to have evolved from neural areas in ancestral species that were used for temporal sequencing or motor control, is not unique to humans. It is found in other species, such as songbirds and elephants, and will appear to be expressed in similar parts of neural tissue.7 Yet the human and chimpanzee versions of FOXP2 differ by just two amino acid positions, underscoring the extent to which the genes involved in language are likely to be tinkerings with preexisting machinery rather than whole new innovations.

If there is a lesson to be learned, it is this: We are ever to understand ourselves fully, we will first need to understand from whence we came.

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**References**


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**Gary Marcus, associate professor of psychology at New York University, has published in a number of the roots of human language acquisition and builds computer models of the development of brain and cognition. He is author of The Birth of the Mind: How A Tiny Number of Genes Create the Complexities of Human Thought (Basic Books, 2004).**
Beholding the Talking Chimp

By Gary Marcus

From our common ancestor with chimpanzees, it took only six million years, give or take, to develop the ability to speak. And, as we now know, the vast majority of our genetic material has been unchanged. Language, and whatever else separates us from chimpanzees, has its origins in alterations to no more than about 1.5% of the genome, a pretty neat trick, when you consider that handy talking can be remarkably subtle changes. For instance, a big part of what underlies language is the ability to represent what linguists call hierarchical structure, small units containing larger units. Consider two sentences that in turn form still larger units: an article (the) and a noun (girl) coming together to form a noun phrase: a verb (loves) and the noun phrase coming together to form a verb phrase (loves the girl); another noun phrase combining with the verb phrase to form a sentence (The sailor loves the girl); and that sentence combining with other bits to form still further sentences (Mr. Lynch knows that the sailor loves the girl).

That may have opened the way to the rapid expansion of the human brain, which is about four times the size of a chimp’s. But size isn’t everything. While a human-sized brain might be a necessary prerequisite for language, it is hardly likely to be sufficient. And elephants have significantly larger brains than ours, but they don’t have anything as complex as human language. Only with further evolutionary changes to our brains, perhaps in the last 100,000 years, did our ancestors begin to talk.

Isolating those further changes won’t be easy. Although any one with an Internet connection can now pore through the two 1 billion-nucleotide-long sequences that constitute the genetic heritage of man and chimpanzee, identifying the paths to language will require not just spotting the differences (the vast majority of which may have little to do with language), but putting those differences in the context of a significantly improved understanding of how the brain acquires and produces language. If the differences are considerable, but I believe this understanding will come into focus as we increasingly view language through the lens of its hierarchical nature and its reliance on preexisting biological mechanisms.

Language Barriers
At the moment, the most obvious obstacle is still that of language. Although sciences have become quite proficient in working with genes and in studying the brain, we still have a long way to go. We can measure the activities of genes by the thousands, but when it comes to neurons, we’re still limited to measuring a handful at a time (with so-called single-cell recording techniques) or measuring the gross activity of hundreds of thousands of neurons, which makes it very hard to see how we can fully understand which genetic changes were crucial for the evolution of language. Until we have a firmer grasp on what human-specific neural changes were crucial for the language’s evolution, all that we can hope to do is to search for markers that correlate evolution and language.

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Area for grammar, Wernicke’s Area for meaning) and stimulated a great deal of research, aimed at understanding language as the product of a far more complex network that spans the brain. Although it is too early to tell for sure what we will discover, my research into the interface between language, genetics, and neurosciences leads me to predict that the genetic and environmental influences of preexisting parts will converge on two fundamental truths.

The Pattern of Pattern First, the biggest difference may lie in the way in which certain forms of FOXP2 differ by just two amino acid positions, underscoring the extent to which the genes involved in language are likely to be tinkerng with preexisting machinery rather than wholesale innovations. If there is a lesson to be learned, it is this: if we are ever to understand ourselves fully, we will first need to understand from whence we came.

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