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Shifting Gears: Seeking New Approaches for Mind/Brain Mechanisms

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Abstract

Using an autobiographical approach, I review several animal and human split-brain studies that have led me to change my long-term view on how best to understand mind/brain interactions. Overall, the view is consistent with the idea that complex neural systems, like other complex information processing systems, are highly modular. At the same time, how the modules come to interact and produce unitary goals is unknown. Here, I review the importance of self-cueing in that process of producing unitary goals from disparate functions. The role of self-cueing is demonstrably evident in the human neurologic patient and especially in patients with hemispheric disconnection. When viewed in the context of modularity, it may provide insights into how a highly parallel and distributed brain locally coordinates its activities to produce an apparent unitary output. Capturing and understanding how this is achieved will require shifting gears away from standard linear models and adopting a more dynamical systems view of brain function.

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INTRODUCTION

With all we know about memory and its failings, any kind of retrospective should be suspect. How many times have we called up past experiences that seem key to our lives, rolled them around, and then let current times tag them before putting them back to sleep? Over time, how can our memories possibly resemble the way things truly were?

There is something about the personalities we have known, however, that sticks and seems as true to us in the present as it was the day we formed our opinion about the stuff of certain people. Class reunions are a telling moment. Harry, 50 years later, is still an ass, while Bob is still cool. Even though we have not laid eyes on them since graduation night, the 50 intervening years have done nothing to change our views. On the other hand, and somewhat paradoxically, our ideas on how to understand mechanisms of nature do seem to change. These stubborn realities are fair warning about what follows. In short, my views on the flow of events and ideas that have captured my interests are undoubtedly influenced by all these intangibles.

When I began my intellectual journey of the past 50 years or so, the world and its challenges were to be understood in straightforward ways, with simple models of structure/function relationships being the dominant reality. In animal research, make a lesion, see what happens. Make another lesion, see what happens. In human research, study all patients who happen to have lesions in different places or study surgical patients who have particular kinds of disconnections. Or, in both animal and human physiology, eavesdrop on neurons and see if the neural code that directs behavior can be figured out.

The straightforward thrusts of youth in a scientific field that was itself young are telling and important. Yet what is more important to realize is that scientific progress, as it unfolds in spurts of insight arriving in a field of hard, mundane work, is commonly disorderly and mostly nonlinear. Stuff happens along the way. One influences others and at the same time is massively influenced by others. One of the beautiful things about science is that how one looks at a body of work after it is completed might well pose questions that are different from those that one originally imagined. While this shifting perspective is going on, the experiments conducted sit there, unmistakable and sure-footed. Their ultimate richness, or possible banality, fluctuates as surrounding knowledge and theory accrue to our human culture.

In my case, one overarching truth, which emerges from split-brain research as well as the study of neurological disorders and functional imaging studies, is that the human brain is not an all-purpose centralized computing device. Instead, it is organized in modular fashion, consisting of distributed, specialized circuits that have been sculpted by evolution and development to perform specific subfunctions while somehow preserving substantial plasticity (Gazzaniga 2011).

In the past, when experimental results were consistent with this perspective, it was enough to stop there. Clearly, however, such a formulation begs the question: How does a distributed mechanical process give rise to unitary, functional output? Over the years, many experiences

and new hunches have made me realize that if any deeper understanding of mind-brain relationships is to come about, it would necessitate shifting to a more dynamical systems approach. My animal work, my work on patients, and my endless discussions with students, friends, and colleagues led me to this conclusion. My goal in this essay is to capture this journey of discovery and to illuminate how this view came to be.

THE EARLY YEARS

For me, it all started with a feeling—a feeling about the need to know “What’s it all about?” I can trace it back to my teenage years and often thought it was promoted by being the fourth out of five children of Dante and Alice Gazzaniga. For many years, I was the youngest and was less differentiated than my older brothers and sister. It fell to me to keep the peace in a vigorous family. When my younger sister came along, my role changed as my older siblings shipped out to college and I was left behind to help raise Becky with my parents. Everybody loved Becky, so it was more like the three of us were competing to take care of her.

This is all to say that there are always plenty of social forces around us shaping and modifying our natural dispositions. My disposition was “contrarian.” If somebody said this is the way things are, I was always thinking about the alternatives. In part, this also relates to my many inadequacies at advanced quantification, so I always tried to frame whatever issue was being discussed in more accessible terms. Sometimes it worked wonderfully; sometimes it was a total bust. So, quantitative skills do not come naturally to me. To the extent that I possess any, they were hard to acquire and were never “felt.” When I was a graduate student at Caltech, and for some reason or another I had to learn how to derive the laws of thermodynamics, I did it totally by rote and got through it. After I was done, I can remember complaining to Seymour Benzer that I simply didn’t get it, didn’t feel the laws. Benzer said, “That’s all right, most physicists don’t either.” Benzer was a very gentle man.

This is all presented in the spirit of full disclosure. I am not quantitative, period. And yet for 50 years I have enjoyed a rich intellectual life with scientists who are exceptionally gifted in mathematics. What’s up with that? I once heard Duncan Luce say that statistics should not be taught to psychologists. He felt the newly trained students would come to think that statistics was the important part, not the question being examined. Often we hear specialists talk endlessly about the quantitative details of their research, whereas they are seemingly blasé about the net idea that comes out of all the work. This is the danger Luce was talking about, and I think we all see this happening far too frequently.

More fundamentally, the feeling of being interested in the question of what life is all about is a wonderful center for the mind. Whatever crazy, mindless activity one might be engaged in during the day, whether it be learning historical facts, a foreign language, or how to play football, coming home mentally each night to that question has been a wonderful tonic. One’s mind really is an exclusive island that one can retreat to frequently, if not daily, where no one can bug you, and where one’s own interpretations of the world are continually revised and updated.

Somehow all of this was working on me early in life and found me trotting off to Dartmouth College, where my older brilliant brother Alan was already a star football player and a man about town, soon to enter medical school. His tales of life in Hanover captivated me, and I dearly hoped I would get in. It all worked out, and from the moment I hit the Hanover plain I was in love with it all. The freshman beanie was placed on my head, and for a week I schlepped furniture up and down dorm steps for the upperclassmen. Somehow, it was exciting and refreshing.

Then I discovered Baker Library with its famous Tower Room. One could grab a book, sit in a carrel, and read away the afternoon. I discovered *Crime and Punishment* there and became mesmerized by my new life. To this day, I think of that experience with a fondness that

I am sure is disproportionate. Nonetheless, the world of ideas was upon me.

THE CALTECH YEARS WITH ROGER SPERRY

It wasn't until my junior year that I began to hit my pace. I took a seminar from an experimental psychologist, William M. Smith, and soon found myself working in his laboratory. There is nothing like coming of age, discovering you cannot only read about science, you can also do science. Bill Smith started me on the lifelong process of learning how to do things—how to build gadgets to test ideas. He was a technologist and, in those days, that meant building contraptions. One of these contraptions held the head while other devices measured eye movements. Visual displays were constructed in such a way as to have specified delays in their signal. I suppose this version of “shop” broke the ice and set the stage for the thought that You Too Can Be a Scientist. I also noted that it was hard work.

I lived off campus rather than in my fraternity, a place that became the much-fabled Animal House. It was a zoo, and Saturday night was usually enough for me, so the off-campus arrangement was not only a necessity but also a relief. It was there that one night I found myself reading Roger Sperry's work on nerve growth. Nobody can read his work without being amazed and overwhelmed by its cleverness and power. Sperry was at Caltech in Pasadena, and my family lived in Glendale, only a few miles away. More importantly, my girlfriend lived in nearby San Marino. Bingo, I said to myself. I will work for him in the summer and that will also give me the chance to see my girlfriend. I wrote Sperry a letter, and to my utter amazement, he answered and invited me to have a summer NSF fellowship. Life was good.

The field I was about to enter was then called psychobiology. Trying to find a definition of this term is challenging, as it was made up to describe those interested in the biological underpinnings of behavior, perception, memory, consumption, and motivation.

In later years, it was recast as the biological study of mental processes. Sperry was one of its early practitioners. Indeed, he was the Hixon Professor of Psychobiology at Caltech.

Actually meeting Sperry in his Kerckhoff Hall office was the first of my many meetings with “the man.” His scientific reputation was exceptional, and deservedly so. From neurodevelopment to animal psychobiology, he was the intellectual leader of his time. I wondered what was he going to be like. Would he quiz me about what I knew? Was he going to direct me to do something? Was he even going to be there? This neophyte was nervous. In fact, Sperry was a soft-spoken and sober guy who was not rattled by much. A few weeks before, a monkey had gotten loose from the animal room and hopped into his office and up on his desk. He looked up and said to his guest, “Maybe we should go next door. It might be quieter over there.”

What I have learned over the years is that people have two realities—the everyday person and the “metro” person. Put differently, one is the personal self and the other the public self, which is constructed by the public for the public: It is your job, your reputation, the model the world builds about you. It is usually not you. The metro self idea explains why millions believed John Lennon never died. The metro self lived on in their heads and, of course, that was very alive.

What happens in life is that we can come to live to feed the metro self and to have the metro self tell us what to do as well. It is this thing that isn't the real you running your life, making demands on you and vice versa. Meanwhile, the real you is trying to see your friends, have a drink, and talk about whatever. In my life, 20 years of lunches with Leon Festinger demonstrated that someone who had a large metro self could also be exceptionally personal and not let the metro self intrude (Gazzaniga 2006). Actually, as I think about it, I know lots of people who pull this off.

At any rate, I came to my life in science with a disposition that was and remains insatiable. I did not arrive on the scene with deep theory or sophisticated knowledge. From the start, it

was all about seeing a problem that appeared sensible to me and then starting the process of thinking on your feet, that is to say, trying to solve the problem in front of you. It is the act of solving problems in front of us that eventually leads to larger theories about the way things work. And nowhere does one have to think on his feet more than when studying split-brain patients.

I have always been amused by my colleagues who claim they knew Roger Sperry. I can say with a fair degree of confidence that nobody knew him like I knew him, both the good and the difficult. For five years I spent several hours per week in his office, one on one. We talked about everything—life, politics, science, gossip, you name it. On most of these occasions I would be reporting on the results of my road-trip testing sessions with split-brain patients or the special Saturday sessions we had at Caltech. After we were totally into the research, he would join me at the sessions. He always took copious notes of our exchanges and always asked probing and enlightening questions. It was the best time of my life.

UNCOVERING BRAIN MECHANISMS: THE ROLE OF SELF-CUEING

In studies of the neurologically disrupted patient, certain general principles emerge. For example, patients strive to complete a goal that has been set by the patient's examiner. One might think and hope they are solving a task one way when in fact they are solving it another. The challenge is to identify *the way* they are solving it. Once that identification is made, underlying mechanisms are revealed that are frequently surprising. Overall, investigations reveal one primary constant of evolved mechanisms that emanate from modular systems: self-cueing out in the periphery of the information processing system that automatically occurs outside of central design and control. Let me give an example from a simple bedside test.

Case D.R. is a split-brain patient from the Dartmouth series of cases. After her surgery,

she showed all the standard disconnection phenomena. Visual information did not transfer between the hemispheres, nor did tactile information. Her left hemisphere was dominant for language and speech while her right functioned at a lower cognitive level, being able to recognize pictures but unable to read.

We wanted to examine her motor control capacity. I asked her to hold out her two hands, fists closed; that was the starting position for each subsequent command. Next I asked her to make the hitchhiker gesture with her right hand. She did so instantly. I then asked her to do the same thing with her left hand. She also did that quickly. I asked her to make the A-ok gesture with her right hand. Again, she did so quickly, and when asked to do it with her left hand, she complied with no problem.

Here is where learning begins when testing neurologic patients. One has to make sure that the task a patient is trying to complete for you is being done the way you imagined it would be done. In this case I knew the patient had undergone split-brain surgery. I knew there was tremendous variation on how well a disconnected hemisphere could control the ipsilateral hand. There never was a problem in controlling the contralateral hand because both the sensory and motor systems needed for such activity were all together in the same hemisphere (Gazzaniga et al. 1967). But controlling the ipsilateral hand was a different story. How did the dominant left hemisphere get the motor messages to systems that control the left hand? After all, those systems were mainly managed by the disconnected right hemisphere.

The first patient I had studied at Caltech 30 years earlier was Case J.W. (**Figure 1**). He was remarkably unable to control an ipsilateral arm and hand while having little problem controlling the contralateral arm and hand from a particular hemisphere. This is quite a dramatic situation, and many of the original split-brain stories about two minds instead of one being in our skulls came from that clear behavior. But as more patients were added to the study pool, many began to show good control over the ipsilateral arm as well as the contralateral arm

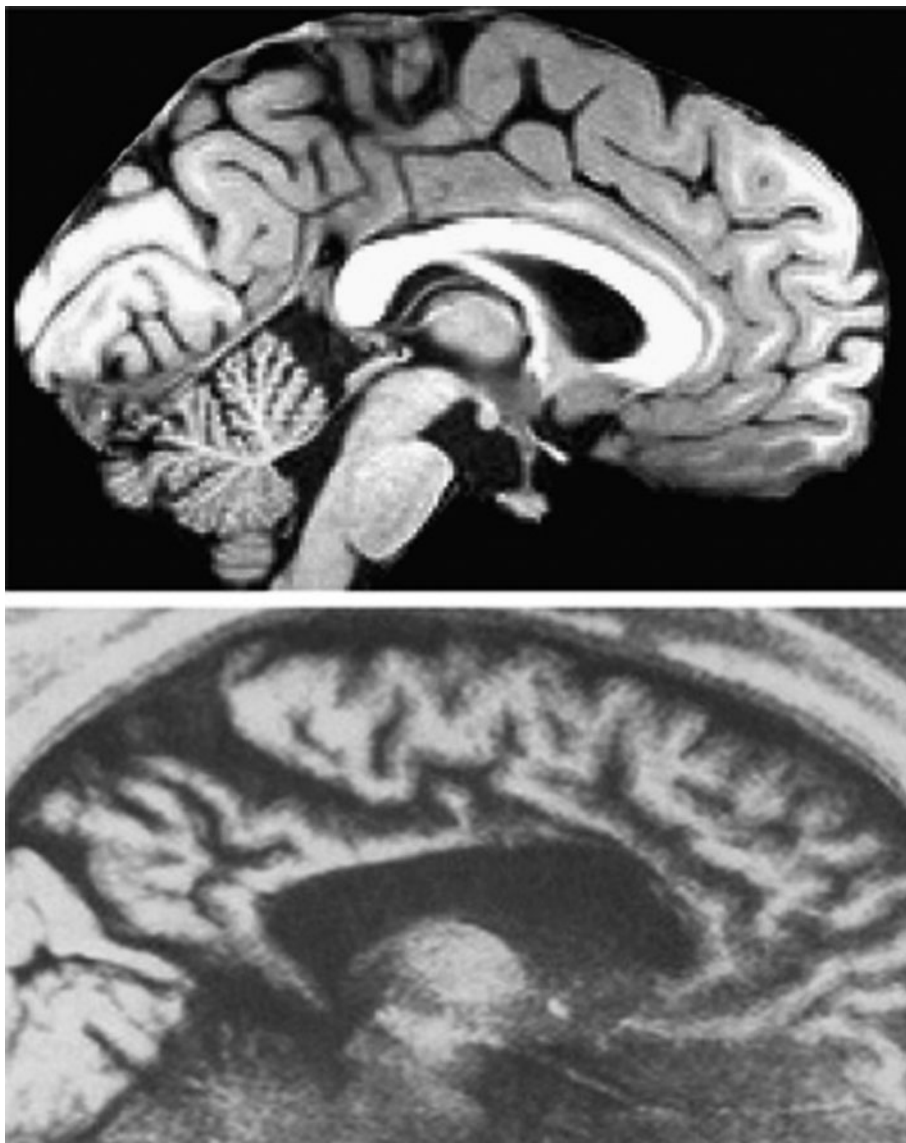


Figure 1

Magnetic resonance imaging of both a normal brain and a split-brain patient (J.W.). The normal brain clearly shows the intact corpus callosum, whereas the scan for a split-brain patient such as J.W. shows its complete absence. J.W. does show the intact anterior commissure, whereas in the first patient, W.J., it had been sectioned as well.

(Gazzaniga et al. 1962, 1967). Yet even when there was good control of the ipsilateral arm, good control over the ipsilateral hand seemed to elude the patients. How did all of this work?

I had intensively studied related issues in split-brain monkeys and determined the

underlying mechanisms to explain this variation (Gazzaniga 1964). All of this was on my mind when Case D.R. was making her hand gestures with both hands. So, knowing that the patient had undergone split-brain surgery and that her dominant language hemisphere

was disconnected from the motor systems of her right hemisphere, I was eager to learn how she was completing the task of controlling her ipsilateral hand so easily. What do you do? Armed with this knowledge, I changed the exam ever so slightly, and bingo, out came the answer.

Instead of asking D.R. to make a hitchhiker gesture first with her right hand, I asked her to make it first with her left hand. She couldn't do it. After she failed, I then asked her to make it with her right hand, which she did instantly. It was the same story with the A-ok sign. If the instruction was for the left hand to do it first, there was no ability to do so (**Figure 2**).

Obviously what was going on was that when the right hand went first, it set up a model and an image for the right hemisphere to see and to copy, which it easily did when the left hemisphere's turn to respond came around. The patient had cross-cued the information from one hemisphere to the other outside of the callosal disconnection. If this were true, then what would happen if the patient was asked to do the task with her eyes closed? With bedside testing like this, that is easily done. The exam continued.

I asked the patient to close her eyes and to make a hitchhiker sign with her right hand, which she instantly carried out. Now with her eyes still closed, I asked her to make it with her left hand. Amazingly, she could not do it. The patient's right hemisphere could not understand the spoken command, and with her eyes closed she could not cue herself by looking at a model to copy, which of course was the right hand. As a consequence, the left hand sat there frozen with inaction.

This one simple bedside test reveals so much. It not only reveals the dramatic disconnection effects of the surgery but also a basic truth about living organisms. We are all about singular, unitary goals, about obtaining the desired behavior as framed in a command to action in the niche that is challenging us. We somehow achieve this unitary output from a highly modularized brain with multiple decision

centers, not just one (Gazzaniga 1985, 2011). How does that all work?

In human patients, where neuronal pathways are disrupted, the goal is achieved through alternate mechanisms and strategies. In this instance, it was clear that the right hemisphere—the hemisphere that has major contralateral control over the left hand—could not follow a verbal command because it was disconnected from the left hemisphere. The explanation might have been, however, that the left hemisphere could have governed the ipsilateral left hand through ipsilateral corticospinal pathways that we know exist (Gazzaniga et al. 1967). Yet we know that that explanation could not be true because the verbal command could not be followed both when the eyes were closed and when the left hand was directed to respond before the right hand. What was going on?

Clearly the right hemisphere could execute the command only when it visually saw a model of the posture being requested. Thus it could follow a nonverbal command and get to the goal in question. The overall system with all of its separate modules had cued itself into completing the goal. This cueing is ubiquitous.

Examples of self-cueing come at almost every level of study: Cueing is how disconnected modules solve the puzzle of coordinating their separate skills to complete a goal. Another example comes from watching Case J.W. carry out a command given to his disconnected and silent right hemisphere (although it was able to read some words). I flashed the word "Texas" and asked him what he saw. The left speech hemisphere replied, "Nothing." When I then directed him to draw with his left hand what he had seen upside down, I was stunned to see that without hesitation he picked up a pen and drew an outline of the state of Texas, upside down! (**Figure 3**).

On another test, J.W. was asked to draw with his left hand what he saw. In this test I flashed the word "car" to the left hemisphere and "1928" to the right hemisphere. In this fashion neither hemisphere knew what the other had seen. Could he possibly draw an old-fashioned car? J.W. was a model car enthusiast, and he

knew a lot about cars of all kinds. Yet the hemisphere privy to the command “car” did not know what vintage. The hemisphere privy to vintage did not know whether it was a car or a truck or something else he was to draw. How could he possibly complete the task?

J.W. quickly picked up the pen once again and drew an old coupe (**Figure 4**)! Somehow each hemisphere was contributing to the task, not by synthesizing and integrating the information in the brain, but rather by using the piece of paper. The integration of modular-specific information was being coordinated, perhaps not unlike two people dancing, where one takes the lead. It is true that each hemisphere could initiate and/or stop a movement. With each being able to watch the picture of the car unfold, as one side initiated a command to move the pen in one direction, the other could jump in and override the initial command with the command to stop the movement.

This striking result, which reveals the idea and importance of self-cueing and of independently controlled systems, found its origins in much earlier and unrelated work. During the original split-brain work at Caltech, I carried out an extensive program of subhuman primate research as well. Again, the overall puzzle was why animals that had their brains divided, sometimes far more extensively than ever disconnected in humans, always seemed like they were behaving in an integrated way when it came to carrying out goal-directed behavior. How, for example, was the left hemisphere of a rhesus monkey with a deeply split-brain—a hemisphere disconnection that extended down into the pons—able to control its ipsilateral left hand? We were so committed to the idea that all information came from a central command center, which had to directly connect to particular peripheral muscles, that what we observed at first made no sense to us. Dozens of studies finally revealed one major finding: The animals were engaged in self-cueing. One hemisphere was reading the cues set up by the other (Gazzaniga 1964). Here is how we discovered it worked.

We took high-speed films of split-brain monkeys reaching for objects such as grapes with one eye closed. In animals the optic chiasm was also divided, which means information presented to one eye went only to the ipsilateral hemisphere. So, if we occluded the right eye (and I did this by various means including a specially designed contact lens), only the left hemisphere could see. Then, when one eye was occluded, say the right eye, we filmed how well the two hands retrieved grapes presented to the animal at the end of a wand. With visual information now restricted to the left hemisphere, the right hand was quick and deliberate in retrieving the much-desired grapes. As the hand moved to grasp the grape, the posture of the hand properly formed in anticipation of retrieving the morsel of food.

At the same time, however, when the animal tried to use the left hand, a different strategy was evident (**Figure 5**). Cueing was active at many levels. First, the monkey would orient the entire body toward the general direction of the object. The left, seeing hemisphere had control over gross body posture and orientation and could easily position the entire body in the correct orientation toward the desired point in space occupied by the grapes. As a consequence, the right hemisphere knew, in a general sort of way through proprioceptive feedback mechanisms, where the object was located. Then the left arm would reach out in the direction of the object. The left hemisphere can initiate arm movements and/or signal the right hemisphere to “go.” As a result, the right hemisphere commanded the left hand to start off in the appropriate direction, which it knew because of the proprioceptive feedback (Gazzaniga 1966b, 1969). In short, the right hemisphere knew roughly where the object was on an *X/Y* grid, but it did not know the *Z* dimension. Here was the fascinating part: The left hand remained ill formed and nonanticipatory in getting ready to grasp the object. The right hemisphere couldn’t actually see it, and the left could not control the distal digits of the left hand. As a result, the hand always looked ill posed for

actually grasping the grape—until the magic happened. Eventually the hand bumped into the grape! At that moment, the somatosensory/motor system of the right hemisphere was cued, and it clicked in. The right hand snapped to, formed the correct posture, and grasped the grape, much as we do when we stick our hand into a dark drawer to pull something out—as soon as we feel it, we know how to grab it.

Back-and-forth cueing is going on at all levels and by systems more or less independent of one another. Yet somehow the system stumbles forward to complete the action. Although it now looks like dynamic feedback, in those days we called it cross-cueing, and in fact I did some other experiments related to this idea in the realm of emotions.

COGNITIVE AND EMOTIONAL CUEING

Emotions color our cognitive states almost moment to moment. Older, more subcortical parts of the brain are heavily involved in the management of emotions, and many of the structures have interhemispheric connections (Gazzaniga 1966a). Could emotions experienced by one hemisphere be detected by or have influence on the opposite hemisphere?

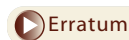
The first experiments were carried out using monkeys. In brief, monkeys were outfitted with goggles that were equipped with a blue lens and a red lens, one color for each eye. Thus, if an animal was experiencing the world in a blue-lit room, only one hemisphere could see—the eye and hemisphere viewing the world through a blue lens. If a red light was on, only the opposite hemisphere could see, and the hemisphere with a blue light saw nothing. In my experiments, the animals viewed a visual task through a specially designed chamber that contained a half-silvered mirror. If the monkey looked straight ahead and only the red light was on, one hemisphere saw a geometric visual discrimination task and the other hemisphere saw nothing. Since the viewing chamber was also equipped with a half-silvered mirror that was invisible, a separate visual image could be projected to

the opposite hemisphere if a blue light flashed on. We wanted to know what would happen to the work pattern of one hemisphere if the other were suddenly exposed to an emotionally laden stimulus, such as a snake. Would the emotionally provoked brain half dominate or subcortically influence the brain half that was engaged in the simple and emotionally neutral task of visual learning (**Figure 6**)?

The answer was clear. The animals jumped back, and the hemisphere that had experienced the emotion cued the rest of the animal by its action. Something was wrong, the discrimination task ceased, and the animal was agitated: cross-system cueing once again.

Cross-cueing also was evident in the cognitive domain, and the work on our patients solidified the idea. Modular or separate systems, cueing each other in order to appear unified, purposeful, and integrated, seemed to be everywhere. As I note, we detected this early on in split-brain animal and human work at Caltech and saw it occur time and again when testing our patients over the next 40 years. We moved quickly from animal studies to human studies and then back to animal studies. In one of the first observations, I was in the process of seeing if simple colored lights could be named in both visual fields in patients who spoke only out of the left hemisphere. In the early days there was always concern regarding whether information of a low level could transfer over from the right hemisphere and be described by the left hemisphere.

During one such study, patient N.G. demonstrated our newly discovered strategy. The test was as follows: If a colored light (say red or blue) came on in the right visual field, which projected to the left brain, there was no hesitation, and it was quickly named correctly. When a light came on in the left field, however, matters changed. If N.G. said “blue,” which meant that the left hemisphere had uttered “blue” and it was “blue,” the patient said nothing else, and we got ready for the next trial. With that kind of overall response, either the stimulus had transferred or the right hemisphere was speaking. At this point we didn’t know the answer.



The telltale trials were when the right hemisphere saw a particular color, for example, red, and the left hemisphere guessed the wrong color, for example, blue. After a few flat-out mistakes, the patient learned a strategy to make it appear she could do such a task. As the left hemisphere would start to guess and say “gree,” it would stop and then guess correctly by saying “red.” What was happening was that the disconnected right hemisphere heard the “gree” being uttered by the left hemisphere and stopped the speech process, or it nodded the head, shrugged the shoulders, or gave some kind of cue to stop the speech emanating from the left brain. That then cued the left hemisphere to change its response and conclude that it must be the other color! The left hemisphere quickly then restated the answer and said the correct color. All of this happened in the blink of an eye.

Steven Hillyard, another person I came to know at Caltech, took an interest in split-brain patients early on, even as an undergraduate at Caltech. Hillyard is by far one of the best scientists I know. He lets the data do the talking and is a stickler for details. He and I were collaborating on a study years after we both had left Caltech and were trying to figure out the language capacity of a patient, L.B. We set up an easy test for the patient. All he had to do was to name numbers (1 to 9), which were flashed to either the left or the right visual field. Normally, we would expect right visual field stimuli to be correctly and quickly named. Thus if a “1” or a “4” or a “7” flashed up in random order, the patient’s left speaking hemisphere would respond correctly. It did, and the reaction time for each stimulus was about the same.

What initially surprised us, however, was that the right hemisphere seemed to be naming all the numbers too. What was going on? Was this our first patient to show transfer of information between the hemispheres? Was this a right hemisphere that could speak? This possibility is always there and must always be checked out.

Hillyard plotted the reaction times for each response, and the strategy L.B. was using became apparent. All stimuli flashed to the left

hemisphere, which is to say any number from 1 to 9, yielded the same reaction time. However, when the same list of numbers was presented to the right hemisphere randomly, 1 was reacted to more quickly than 2, which was reacted to more quickly than 3, which in turn was reacted to more quickly than 4, and so on all the way up to 9. Another cross-cueing strategy revealed! The left speaking hemisphere started counting using some somatic cueing systems such as a slight head bob, and when the number of bobs hit the number that was presented to the right hemisphere, the right hemisphere sent a stop signal, at which point the left knew that must be the number flashed. The left hemisphere said it, not the right (Gazzaniga & Hillyard 1971)! Unbelievable. When we then ran another series of trials where the patient had to respond immediately, the left hemisphere continued to respond correctly and quickly, whereas the score for the right hemisphere dropped to chance.

The constant shifting of strategies and mechanisms to carry out a goal reminds me of the story that Daniel Dennett often tells about great magicians. There are several ways to do every trick, each calling upon a different routine or technique. Ralph Hall was a master at this. Just when someone thought he had identified the way Hall did a particular trick, Hall would change the strategy, thereby dumbfounding his challenger, and carry on with his tricks. The brain does the same thing.

I am not at all sure how conscious I might have been about my continued interest in this sort of constant shifting of strategies of both animals and humans to complete goals no matter how one interrupted the normal mechanisms of neural function were. I was certainly well trained and versed in its many occurrences, which could explain why I continued to be drawn to related phenomena. After a short stint in Pisa, I found myself starting my second academic career at the University of California, Santa Barbara (UCSB) and became captivated and strongly influenced by David Premack. Up to that point, I really didn’t know much about experimental psychology as a science and an approach to understanding the mind. As I relate

below, the idea of cueing and different strategies came up again in a totally different context that was driven, in part, by what I learned from Premack.

THE INTERMEDIATE YEARS

My perspectives on mental mechanisms all changed as I spent most of my subsequent professional life surrounded by the top psychologists of our time: David Premack, Leon Festinger, and George Miller. It was a feast, each so utterly different in nature and style, yet all so incredibly close in intellect, drive, and savvy. You could not spend time with any of them without coming away the better. The one skill they all had was to let the other guy's mind wander (mine, for example) and then, after whatever was on your mind had been said, to go to work on showing it was either hilariously wrong or contained kernels of possible insight. Both experiences were enlightening, to say the least.

I have written about Festinger (Gazzaniga 2006) and Miller (Gazzaniga 1986) elsewhere, so I focus here on Premack, who started me down this trail of friendships. Sperry had always told me that it was psychologists who thought deeply about the mental, not biologists. Now I was seeing it firsthand.

It is difficult to think of a living psychologist more influential than David Premack. When we consider our origins, our history, and our uniqueness as humans, it is Premack who has been our best guide in the understanding of who we are. As I write this, I can tell you that he is still at it, and with more gusto than ever.

Before his pioneering work on the cognitive and the "possible" language capacities of the chimpanzee, Premack untangled the very simple but (at the time) incorrect picture of the nature of motivation. Behaviorists had developed the view that animals were motivated by external contingencies, failing to consider that animals might have internal states and preferences (Premack 1959). Premack turned the entire view of the nature of reinforcement on its ear by looking beyond what was easily

observable. Using the methods of science, he unearthed the underlying principles of what motivates living creatures to act.

He employed these skills in squaring off with chimps, in particular a chimp named Sarah who lived down the hall from me for years when our time overlapped at UCSB. I don't care for chimps. I have always found them too aggressive and bestial, and quite frankly, I would walk in the other direction when Sarah approached with her trainer or with David.

Sarah was no ordinary chimp. She was exceptionally smart and engaging. She was also volatile. Premack perfectly managed her by being even more unpredictable and clever than she had ever seen a human be. This was one *homo sapiens* that always beat her at her own game. Premack established a social relationship with her and then began to use it to explore exactly what was, and was not, in and on Sarah's mind. At that time, Premack was beginning to clarify the intellectual limits of our closest living relative, and in doing so, he began to unearth the factors that make humans unique.

In time I left for New York University and began to study neurologic patients with disorders such as global aphasia. Along with my graduate student, Andrea Velletri-Glass, I began to wonder if a severely disabled human, who evidenced no language or communicative skill, could learn the protolanguage system in which Premack had successfully trained Sarah (Velletri-Glass et al. 1973). With air travel, phone calls, faxes, and later email and the Internet, we began a collaboration with David. We intensely studied several patients and discovered that patients with focal left hemisphere lesions were rendered severely aphasic but could, nonetheless, learn the protolanguage to varying degrees. In other words, their spared right hemisphere could communicate at the level of a clever chimpanzee, but not much more.

Premack's work did not go unnoticed by the University of Pennsylvania. Before we knew it, David and his wife Ann were on a plane with Sarah, headed to Honey Brook, Pennsylvania, where a chimp facility had been specially built in Amish country. It was there,

with Sarah and a small group of young chimps, that Premack gave birth to the idea of “theory of mind” (Premack & Woodruff 1978). We may have a theory about a chimp, about our dog, about an old sweater, but does a chimp have a theory about us? Does the chimp have a theory about other chimps? Does it have some primitive understanding of the mental states of others? As in all breakthroughs, the ingenious way that a question is asked makes the impact. This is another Premack specialty. Premack has the rare ability to turn an issue on its ear, and the idea of whether an animal could have a theory about humans (or anything else) did exactly that. He changed our perspective and opened up a wealth of ideas in the psychological community about our nature and our origins.

The Amish chimp facility was cleverly designed, allowing for a wide range of tests and observations. A torrent of research soon originated, serving as the basis for the landmark book *The Mind of an Ape* (Premack & Premack 1983). One startling observation Premack made was that chimps do not engage in pedagogy. The flip side of the observation is that humans are the only primates that teach their young.

Although a great deal of Premack’s work was rooted in what animals could or could not do, it became obvious to him that babies and infants were a great source of information about our psychological nature. When do babies understand sociality? When do they understand that some social acts are positive and others negative, and do they recognize the preconditions for morality? How could that be tested? Does social intelligence develop as the result of experience? Or is it there from infancy? Premack and his constant companion in every aspect of life, his wife, Ann, pursued these questions and developed a psychology of the affect and emotion of the newborn. Of course, others had studied infants, but these questions were tested in a novel way, which is captured in their book, *Original Intelligence: Unlocking the Mystery of Who We Are* (Premack & Premack 2003). David Premack is an example of this truth: We don’t all have to be smart—just a few can make a difference. His ideas and research are singular.

We are all influenced by others, and these influences pop out in many ways. While I was spending a lot of time stewing about cueing, I obviously was also listening. In what later became known as the Premack Principle, he showed that what served as a reinforcer was reversible and could be predicted by the preference structure of an animal. Thus, a rat deprived of running would drink water, if that gave it the opportunity to run. Conversely, if a rat was deprived of water, it would run in order to have the opportunity to drink. This was a powerful idea and it stuck with me. When I moved to New York University, Premack gave me one of his unique testing systems to take along to investigate an idea I had. Would an adipsic rat (a rat that will not drink as the result of a lateral hypothalamic lesion) drink if given the opportunity to run? If the answer was yes, it would urge a more dynamic view of brain function and caution against the ever-growing tendency to see static models relating structure to function. In fact, we learned adipsic rats gladly drank if that was what they had to do in order to run (Gazzaniga et al. 1974).

There it was again—a different strategy allowed a dynamical system, the brain, to accomplish a goal. In this case, the observer was creating new contingencies that evoked the different strategy, but this investigation also revealed it was a dangerous proposal to say that one had discovered any particular brain network underlying the motivation to drink water. It was a striking finding and, I might add, largely ignored!

Once I was hooked on the idea, I tried all kinds of experiments to further the demonstration that these are inherently dynamical systems. In one wild experiment, I tested monkeys who had undergone inferior temporal lobe lesions that rendered them unable to learn visual discriminations for a food reward. I wondered if they would learn the new discriminations if they were given the opportunity to run in a large monkey wheel I had specially built for them. What I discovered was that monkeys hate to run in a wheel. Instead, they would engage the game of visual learning in order to lock the wheel so

it wouldn't move (Gazzaniga 1978)! Capitalizing on that preference, I saw some evidence of learning. Same point, different species.

THE INTERPRETER

It struck me a few years back that it took 25 years for us to ask the right question in one of the perceptual/cognitive settings of our patient testing program. In the early phase of split-brain testing, we were constantly testing to see if visual information of any kind was cross-communicated from one hemisphere to the other. We were also looking into possible extinction phenomena such that the failure to report left field stimuli in split-brain patients might be related to that well-known clinical symptomatology. Accordingly, after flashing information to either visual field or to both simultaneously, we would ask split-brain patients, "What did you see?" The patients would dutifully respond and describe information that was solely projected to their right visual field. No surprise, and all was copacetic.

Finally, Joseph LeDoux and I stumbled across the right question to ask. First we changed how we asked the patients to respond. We gave each hand a multiple-choice option. The left hand was free to choose one of four pictures that best matched the left visual field stimulus. The right hand was free to choose one of another four options to match stimuli presented in the right visual field. With the task set up in this fashion, we could change our question. Instead of asking what the patient had seen, we would let each hand respond and then ask, "Why did you do that?"

The disconnection story, with its huge effects evident even at the bedside, was well known and established. We were not ready for the huge insight this slight manipulation of the standard test would yield. We felt we were simply fishing around to discover why each patient seemed so utterly normal in everyday life, so integrated. Each patient managed his life with singular purpose, drove to work in some instances, raised children, and enjoyed the this-and-that's of everyday life. We couldn't

figure out why their disconnected state wasn't more disruptive. The answer came one day in a snowy trailer park in Burlington, Vermont, when we tested patient P.S.

P.S. was one of the first patients from the Dartmouth series of cases that we studied in detail. We had a chance to work him up both pre- and postoperatively, first in Hanover and then at his home, after surgery. He was a major case, as he was one of the first patients in the East Coast series to show all of the lateralized phenomena we had demonstrated to exist in the Caltech series. Speech and language were lateralized to his left hemisphere, and visual-motor skills, such as being able to draw three-dimensional objects, were possible only from his right hemisphere. In many ways he was an exciting confirmation of all the earlier work, and he had been operated on by a different surgeon.

One could have stopped there and declared success. Each side of the brain could work on its own problem without getting confused with the other problem. It could organize the correct response and carry it out. In short, there was no blanking out by one hemisphere when the other was working. But as I just reviewed, we would have missed the boat if we had stopped there. One of us had the good sense to ask P.S. the question, "Why did you do that—why did you point to those pictures?"

It was his answer, which we knew came from his left brain, that gave rise to the concept of the interpreter. There appears to be a special module in the left hemisphere that makes up an explanation for why all the modules do what they do. It is the mechanism for generating our narratives; it is the thing that keeps a storyline going in all of us and that tries to make sense out of the many independent functions we have going on at any one time. In this instance, Case P.S. had seen a chicken claw with his left brain, and his right hand chose a picture of a chicken. His right brain had seen a picture of a snow scene, and his left hand picked up a picture of a shovel. When asked why he had done all of this, he said from his left hemisphere, "The chicken claw goes with the chicken, and you need

a shovel to clean out the chicken shed” (Figure 7).

There it was. It took 25 years to ask the right question, and in doing so, perhaps the most important finding from all of split-brain research was revealed. One of our seemingly infinite modules generates the storyline as to why we do the things we do, feel the things we feel, and see the patterns in our behavior that contribute to our theory about ourselves. Once you see it at work in this simple experiment, you see it everywhere. The responses from discrete modules pour out of all of us, and evolution invented a module to make it all seem like it pours forth from a “self.”

My students and I have seen this time and again over the past 25 years, and each of us has our favorite examples. In digging through old videotapes of our experiments, I came across one. Case J.W. was flashed the word “smile” to the right hemisphere and the word “face” to the left hemisphere. He was simply asked to draw what he sees. His right hand drew a smiling face. “Why did you do that?” I asked. He said, “What do you want, a sad face? Who wants a sad face around?”

In a very recent test on Case V.P., my colleague Michael Miller was examining the unlikely proposition that the hemispheres of the brain may manage different dimensions of moral decisions. Prior brain imaging work on neurologically normal subjects suggested that the right temporal-parietal junction was involved in tracking the beliefs of others while the left hemisphere managed one’s own beliefs (Saxe & Kanwisher 2003). This would suggest that someone with a lesion in the right hemisphere temporal-parietal junction might not consider the beliefs of others when making a moral decision and thereby would be more prone to utilitarian beliefs, beliefs that had meaning only for one’s self. There is such evidence. It also would predict that a split-brain patient, when talking about his choices on tests that probe such moral values, might be more utilitarian in his outlook than would normal controls. After all, and because of their callosal disconnection, the area of the brain managing

the beliefs of others was now disconnected from the part of the brain considering a moral dilemma from the perspective of the personal self (Miller et al. 2010). Incredibly, that is exactly what was found. But Miller and his colleagues didn’t stop there. They asked the patients why their answers reflected a lack of concern for the other person’s well-being. Each time one could hear the interpreter jump in and spin the story.

In one example, J.W. was read a scenario in which a waitress intended harm toward a customer by serving him some sesame seeds, believing the customer was highly allergic to them. As it turned out, the customer was not allergic to the sesame seeds, and he was fine. However, when J.W. was asked whether the waitress’s action was permissible or forbidden, J.W. responded on the basis of the outcome and not the belief, i.e., he said it was permissible. Moments later, though, as if that didn’t seem right to his verbal left hemisphere, he spontaneously offered that “sesame seeds are tiny little things, they don’t hurt nobody” (Miller et al. 2010). This rationalization offered by J.W.’s left hemisphere seemed to defend his immediate response, which was based solely on the outcome.

THE GIFFORD LECTURES AND MOVING FORWARD

Psychologists all feel the tug—an insatiable desire—to carry on the quest to know more about the situation in which we humans find ourselves. Thinking about these things is what the Lord Gifford lecture series in Scotland is all about, and I was invited to give Gifford lectures in 2009. Though submitting my own perspective in that forum was as scary as it was heady, it did give me the opportunity to step back and look at the flow of my own life and to examine how my thinking on mind/brain issues has evolved. It also focused me on what I would like to do moving forward. In a word, it was a time to abandon the car-mechanic view of mechanism that most of us possess and move on to thinking about dynamical systems.

The fields of psychology and neuroscience have been dead set on an overall model of how things work. In a phrase, we want a beginning, middle, and end. Things start at A, progress to B, with an outcome of C. In psychological terms, things start with sensation and perception, progress to associative mechanisms, and then to motor systems. In neuroscience, information arrives in sensory centers, becomes integrated into a percept, and then is fed to various associative cortices and finally to a motor neuron system for execution and movement. The model, by its utter reasonableness, is ingrained in us as to how things must work and how anyone must approach understanding anything. A beginning, a middle, and an end.

Beginning five or more years ago, a stirring among many scientists began to pick up in speed. In the study of action, in particular, an idea that has held up until relatively recently is that cortical motor neurons direct a lower motor system in some way to carry out a task. On top of the commanding neurons is the “will” to make those commands: One is free to decide what to do. This idea has given way to a much more dynamic model of action in which the entire system is running 24/7, with its purpose to do something: to act. It is full of Bayesian priors and internal complexity, and its ultimate goal is achieved by integrating the sensory information available to it. It is automatic, just like another machine, and it is relentless. Alas, there is no more beginning/middle/end model of the world.

Leibniz saw this years ago with his mill analogy. In his 1714 *La Monadologie*, he asked his readers to imagine an enlarged view of the workings of a mill so that all the individual parts could be seen such that one could walk between them. All you find are mechanical components that push against each other, and there is little if any trace of the function of the mill as a whole (Bassett & Gazzaniga 2011). When this analogy is applied to the modern problem of mind/brain research, one realizes that the physical parts of the brain are decomposable, but the mental parts are indivisible. They are realized at another level of organization, where the parts

interact to produce another coarse-grained system or layer. There is limited value in studying the parts alone. There is a deep need to capture how the elements interact in the whole schema of a functioning system (Doyle & Csete 2011). It is like trying to grab hold of mercury. It is a much harder problem than the one most of us were raised on, but it must be recognized that it is the problem.

During the past 50 years, of course, huge advances have been made throughout biology, neuroscience, and cognitive science. Scientists are beginning to consider whether there is what one could call a universal architecture for information-processing systems of any kind, studied at any level. One of the catchall phrases that runs through this kind of thinking is that all information systems are highly “modular.” In neuroscience, this has specific meaning, with more locality and local circuits being discovered all over the brain. It is as if as the brain became more engaged with the environment and acquired more adaptations, it needed more local command centers with low-energy and short connections to handle the routine responses to the increasing needs of a more adaptive system. That, I think, is a fairly well-established truth.

At a totally different level, large corporations adopt a modular model. Coca Cola, for example, has some 300 bottling plants around the world. Because it becomes unwieldy to command such a diverse set of operations from a central source, in this case, from corporate headquarters in Atlanta, local control and operation are used.

The need for modularity in cognitive models is well known, and it is now commonplace to recognize this overall structure. From my perspective, this sort of framework makes total sense. The entire corpus of split-brain work is full of observations revealing the modularity of brain organization. The various lateralized specializations of the left and right hemispheres started everyone thinking about the overall issue. This view of the overall brain architecture was consistent with studies at every level of examination, from visual-motor control, to perceptual skills, and up to language skills and

social moral adjustments. The underpinnings of our mental life were happening throughout the workings of a vastly parallel and distributed system.

One of the most dramatic demonstrations of brain modularity comes from our studies of Case P.S., who began to be able to speak out of the right hemisphere as well as the left hemisphere. This ability increased over time but started out simply enough. We always ran simple naming tasks, tests where each visual field was probed with pictures and words. Normally, a split-brain patient names the right visual field stimuli with speed and accuracy. The left visual field stimuli go unnamed because they were solely projected to the right hemisphere. Starting a year or two after surgery, P.S. began to name visual stimuli in both fields (Gazzaniga et al. 1979). We determined it was not visual transfer by showing that he could not say whether two objects that were presented, one to each visual field, were the same or different. Somehow the right hemisphere was now speaking.

In a sense we were not confronted with two systems, each housing untold numbers of modules, but rather we were simply looking at two super modules, each trying to say what is on its mind in a coordinated and sequenced way, sort of like an old couple who have been living together far too long.

In a free-form conversation with Case P.S., it would be virtually impossible to detect at least two large modular systems interacting to produce a coherent, articulate story line that seemed utterly normal in every regard. But as we discovered, that dazzling unitary speech behavior is the product of discrete modules that are massively self-cued to appear coherent despite being of isolated and rather independent modules. An understanding of this situation would provide insight into how the entire system might work. Experiments were needed.

A second patient, Case V.P., began to speak from the right hemisphere as well. We began to focus on this development and started our explorations by asking V.P. to say compound words that were quickly flashed and

presented visually across the visual midline. My favorite example is when we presented the word breakfast across the midline such that “break” appeared in the left visual field and “fast” was presented to the right visual field. This meant, of course, that the right hemisphere saw the word “break,” and since it didn’t know whether another word fragment was projected at the same time, started to say “bre” as in “brake.” Almost instantly, V.P. stopped saying it that way and corrected herself, saying “breck” because her left hemisphere (which has to finish the word) knows its fragment is “fast” and thus knows the first phonemes must sound like “breck” instead of “brake.” Independent modular systems were cueing the other, so the desired goal was achieved. It is sort of a brain version of a “don’t ask, don’t tell” policy. Everything remains independent but it all cooperates toward a final goal.

Needless to say, a highly modular view of the brain begs more than one question. Why is it that we feel so much psychological unity in our everyday lives? Why do we feel so strongly that a unified self calls the shots, experiences life in particular ways, and is indeed us? We all have a narrative about ourselves, yet we are learning increasingly more about how utterly distributed the processing systems are throughout our brain and that they work rather independently. How can all of this come together?

The radical truth to emerge from split-brain research, the study of neurological disorders, and functional imaging studies is that the human brain is not an all-purpose, centralized computing device but rather is organized in a modular fashion, consisting of distributed, specialized circuits that have been sculpted by evolution and development to perform specific subfunctions while preserving substantial plasticity (Gazzaniga 1985, 2011). The question is how a distributed mechanical process gives rise to unitary, functional output. A debate in cognitive science has been whether a dynamical system or traditional computational framework is more appropriate for describing this process. Within the complex systems community, it is recognized that these two perspectives are not

at odds. What is needed is a compelling computational description of how unitary output can arise from noisy, fast dynamics in many-body systems, and what role competition, operating at multiple spatial and temporal scales, comes to play in this process (Bassett & Gazzaniga 2011, Gazzaniga et al. 2009).

My scientific goal over the coming years is to try to provide an empirically grounded account of how functional states of mind arise from the collective mechanical states of the brain. It is one of the most intriguing problems solved by nervous systems—how cells coordinate their behavior using multiple spatial and temporal scales to generate adaptive behavior. This goal needs all the help it can get.

INTERACTING MODULES: THE VAST UNCONSCIOUS

Characterizing our overall architecture as being modular in nature, and further that the modules interact in purposeful ways outside our conscious awareness, is almost a truism. Any reflection on how our brain accomplishes all the things we consciously enjoy makes it clear that the heavy lifting for our human mental life goes on automatically and beyond conscious control and can even involve our somatic system (Valero-Cuevas et al. 2007). This reality, nonetheless, needs experimental support and revelation. Split-brain research has had more than its share of studies that manifest this truth.

In the contemporary experimental psychology literature, a number of studies have focused on how subliminal stimuli can facilitate or inhibit subsequent perceptual or semantic judgments, although, in general, the results of such efforts have been limited to small changes in response latencies. In contrast, in the neurologic patient, the impact of nonconscious processes on behavior can be much more striking. For example, it has been widely reported that patients with lesions of the visual cortex are able to direct their eyes or point to visual stimuli that they deny having “seen.” Additional findings in the neurologic literature include the ability of amnesic patients to acquire motor and

problem-solving skills with little or no recollection of the training session, and the capacity of patients with parietal lobe lesions to use visual information in an “extinguished” hemifield for cognitive judgments (Volpe et al. 1979) (**Figure 8**).

Probably the most direct evidence of nonconscious processing comes from the human split-brain literature. In previous split-brain studies, it has been shown that behaviors can be elicited from a mute right hemisphere in spite of the fact that they originate outside of the conscious awareness of the dominant left hemisphere. Moreover, in patients with partial posterior callosal section, information presented to the right hemisphere can be transmitted through remaining anterior fibers in a fragmented form. Ultimately, the unstimulated left hemisphere can infer what was presented to the right hemisphere (Sidtis et al. 1981).

In one dramatic study on Case J.W., we showed that nonconscious processes can control overt behavior by demonstrating that information presented to the right hemisphere can influence a left hemisphere-specific response, even though the left hemisphere is completely unaware that it possesses the information for the correct response (Gazzaniga et al. 1987). In this experiment, either the number 1 or 2 was flashed to the left or right visual field. Case J.W. was required to name it or write it out. He was able to correctly name the numbers in either visual field. Through several control experiments, it became evident that J.W. had not developed right hemisphere speech. Nonetheless, somehow the right hemisphere was communicating which of the two options to report from the left hemisphere. What was so striking, however, is that even though the left hemisphere was calling upon this information for its correct verbal and written response, it could not use the information in making a simple, conscious, match-to-sample judgment. Modules were interacting and working at one level, but they were using mechanisms not accessible by conscious processes.

It should be noted that it was not clear how the information presented to the right

hemisphere was transmitted to the left hemisphere. Simple cross-cueing strategies seen in our other tests did not appear to be active in J.W. If cross-cueing, which had been traditionally viewed as a conscious process, were active, the left hemisphere would be aware of the nature of the information and would be able to respond in the between-hemisphere comparison tasks.

It remains possible that a new kind of cross-cueing strategy was active, one that worked totally outside the realm of conscious awareness. Overall, given the pattern of the results, it would appear that the transfer of information was neural in nature. Consistent with this view were the findings of other studies done with J.W., where it was shown that early responses in the visual evoked potential were different for the 1 as opposed to the 2 when flashed in the left visual field but not the right. That finding suggests visual information was being encoded in a different way and that information was transmitted to the left hemisphere. Also, given the callosal disconnection, it would appear that the information was communicated via subcortical structures, although the possible role of the intact anterior commissure cannot be ruled out. It seems that the nature of the communicated information is noncognitive and establishes some kind of simple response readiness in the left brain for one of two possible responses already known to the left hemisphere.

Taken together, observations like the foregoing reveal that the modules that make up our conscious thought interact and process information commonly and automatically. Although psychologists are committed to the chore of ascertaining what we take to be the cognitive variables in decision making and the like, the successful interaction of peripheral modules may well be where the larger problem lies in identifying how mind/brain layers interact.

A FINAL WORD

Early in my life, I did start with some mighty lofty questions, like what are these beliefs we humans carry around by the bucketful, and how

are they formed? Beliefs are what make human life special and worth living. Each of us has them, and each of us sees many of them turn into values. We kill each other, rescue each other, love each other, and hate each other because of beliefs.

We know a lot about beliefs. We can get outside of them and learn how they are formed and indeed some of the brain parts that construct them. We also know how our brains are built and organized, with each brain possessing thousands if not millions of discrete processing centers, commonly referred to as modules or instincts. Most of these modules work outside of our conscious awareness, and most of them secrete their influence on us by biasing our responses to our daily challenges. As Mark Twain said, "Any emotion, if it is sincere, is involuntary."

As those churning, unconscious systems react to our experiences, making us feel one way or another about something, they produce powerful mental experiences. One of our other brain modules, the interpreter module, notes the cacophony of reactions of all of the modules and constructs theories and beliefs as to why we act and feel the way we do. It is this system that gives each of us our own personal narrative—our story.

Many people are resistant to this model of human existence. Although no one has a problem with the idea that things like clocks work automatically and human cells work automatically, people do not like the idea that the brain works automatically. If that were true, it sort of suggests that we would be forced to believe we are simply along for the ride—that the real work for mental life is being done automatically by the brain. Where are we in that framework? There seems to be no room for the phenomenal self and the entity in charge of our actions.

That is the wrong way to think about it. We are what we do, what we experience, what we learn. We humans build stories and theories about it all, and we live within those stories, those interpretations of all of these constantly impinging experiences. That is what we are and that it is how it works. Full stop.

So, we humans are built in certain ways and indeed have certain moral rules that are there in newborn babies and aging adults. What is different about us is that we all cook up different beliefs about why we respond the way we do. Our variation comes from that interpreter giving each person his own spin and story—because each of us draws on different experiences.

Many times the stories of others seem preposterous. It can be their religious story, their political story, or their philosophy of life. They can annoy and irritate and leave one trembling with the sense of superiority, the sense that the other person is uninformed while one alone has it right. Yet, as the great physicist Max Born said, “The belief that there is only one truth, and that oneself is in possession of it, is the root of all evil in the world.” Take a step back when you feel this way. Think about it a minute and appreciate that after all everything is a story—yours as well as the other guy’s.

This overall view of life and mind didn’t just appear from life. It was derived, at least to a

large extent, by my professional work, by trying to understand mind/brain relationships. It comes from seeing how a very special group of human beings, the wonderful patients I have studied for 50 years, have revealed great secrets about how the brain does construct our mental lives, and by knowing those secrets, what it means for us all. There are, of course, always differing interpretations of studies in the area of brain and mind. That reality reminds me of the story about two members of a rabbi’s congregation coming to him to resolve two conflicting statements, and after each finishes with his version, the rabbi says, “That’s true.” They then ask, “But Rabbi, if I what I say is true and what he says is true, how can they both be true?” And the rabbi says, “That is true too.” What is so exciting about science, of course, is that science is always both true and valid for all. The interpretation we give a datum can be dead wrong, but the underlying observations, if done properly, are rock solid. I know that one of the beauties of split-brain research is that the underlying observations are rock solid.

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Figure 2

In this simple bedside test, a split-brain patient can easily carry out a spoken command to make a particular kind of gesture with the right hand. The left hand can subsequently make the same gesture as long as the eyes are open. However, if the examiner's first request is to make a particular gesture with the left hand, the patient fails to do so. See text for an explanation of the cueing involved.



Figure 3

The word “Texas” is presented to a patient’s left visual field, which solely projects to the right hemisphere. The left dominant speech hemisphere says it didn’t see anything. Nonetheless, the left hand, which gets its major motor control from the right hemisphere, is able to draw a picture of Texas in any orientation. The patient explains, “I don’t see the word, then I start drawing something and then it starts bringing what the word was. It’s almost like the left hand was telling me what the word was when I am startin’ to draw. . . . It’s almost like I got this left side telling me what the word is after I put it in motion, which sounds stupid. . . ‘cause I don’t think I see it and then I start going here and something clicks and says what it was.”



Figure 4

A split-up command is presented to a patient. He is simply told to draw what he sees. In this task he has to integrate “1928” solely projected to the right hemisphere with “car” solely presented to the left hemisphere. He fails in judging whether the two commands are the same, but using his left hand he is able to draw a car of the correct vintage.



Figure 5

Split-brain monkeys were examined to discover how one disconnected hemisphere could successfully guide the ipsilateral arm/hand toward a discrete object in space. The studies revealed that the seeing hemisphere first oriented the whole body toward the object, which cued the nonseeing hemisphere the *X* and *Y* coordinates of the object. Subsequently, the appropriate ipsilateral hand posture was formed only when the hand touched the object, thereby cueing the nonseeing hemisphere via touch information.

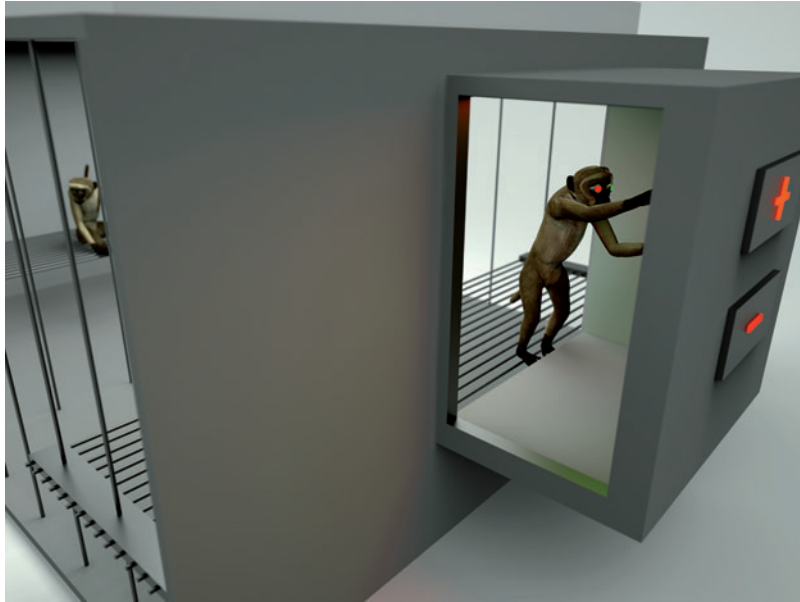


Figure 6

A special testing apparatus and cage were built to test for cross-cueing in the monkey. The animal viewed a visual discrimination task on a panel, and the entire area was illuminated in either red or blue light. The animal viewed the task through a half-silvered mirror device that allowed another object to be presented intermittently, with the aim of determining whether such events would interfere with the animal's behavior.

[Erratum](#)



Figure 7

In this test, a simple match to sample task was presented to each hemisphere (Gazzaniga & LeDoux 1978). The patient was asked to find the matching stimulus from a group of four pictures. After the patient responded, he was asked, “Why did you do that?” The discovery of the “interpreter” modules resulted from this kind of study.

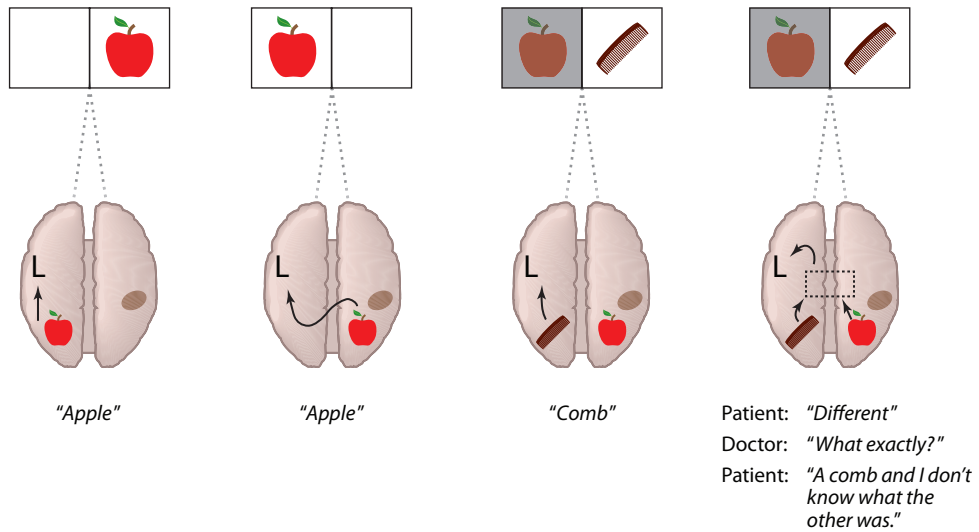


Figure 8

This composite picture represents each of the experimental paradigms. The two pictures on the left describe the typical left and right single visual field naming trials. The two pictures on the right describe a typical response during the simultaneous bilateral visual field trials in the same/different paradigm.