Neuron
Perspective

The New Science of Mind and the Future of Knowledge

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Understanding mental processes in biological terms makes available insights from the new science of the mind to explore connections between philosophy, psychology, the social sciences, the humanities, and studies of disorders of mind. In this Perspective we examine how these linkages might be forged and how the new science of the mind might serve as an inspiration for further exploration.

Ever since Socrates and Plato first speculated on the nature of the human mind, serious thinkers have sought to understand themselves and human behavior in general. For earlier generations, that quest was restricted to the intellectual framework of philosophy. In the late twentieth century, however, a school of philosophy concerned with the human mind merged with cognitive psychology, the science of the mind; both then merged with neuroscience, the science of the brain. The result was a new, biological science of the mind. The guiding principle of this new science is that mind is a set of processes carried out by the brain, an astonishingly complex computational device that constructs our perception of the external world, fixes our attention, and controls our actions. Many people—including policy makers—are beginning to realize that the central challenge confronting science in the twenty-first century is a better understanding of the human mind in biological terms.

Two world leaders have already responded to this challenge. Shimon Peres, the president of Israel, announced at the 2013 World Economic Forum that the lack of a firm biological understanding of the human mind is one of the great problems confronting the world. He initiated the million-dollar Global B.R.A.I.N. Prize for breakthroughs in brain science that translate into treatments of brain disorders. In his 2013 State of the Union address, President Barack Obama independently boosted brain science with the announcement of a massive, multibillion-dollar public and private initiative to understand the human brain. In years to come, this BRAIN initiative may provide a scientific basis for understanding all brain disorders—not just psychiatric disorders, but neurological disorders as well, especially Alzheimer's disease, Huntington's disease, and amyotrophic lateral sclerosis.

The opportunity to understand our mind in biological terms opens up the possibility of using insights from the new science of the mind to explore new linkages with philosophy, the social sciences, the humanities, and studies of disorders of mind. My purpose in this Perspective is to examine how these linkages might be forged and how the new science of the mind might serve as a font of new knowledge. I describe four interrelated and potentially fruitful points of contact where the new science of the mind is well positioned to enrich our understanding of another area of knowledge and, in turn, be inspired to explore further aspects of mental functioning.

- Neuroscience Links to the Humanities, Philosophy, and Psychology: Conscious and Unconscious Perception and Unconscious Instinctive Behavior
- Neuroscience Links to the Social Sciences, Ethics, and Public Policy: Free Will, Personal Responsibility, and Decision Making
- Neuroscience Links to the Perception of Art: The Beholder's Share
- Neuroscience Links to Disorders of Mind: Psychiatry, Psychoanalysis, and Psychotherapy

These four points of contact are likely to give us not only particular insights into specific areas of the social sciences and humanities, but also into new approaches to understanding conscious mental processes. Along the way, we may be surprised to find that biologists have learned the importance of unconscious processes in our mental life—not just our instinctual life, but also aspects of our free will, personal responsibility, and decision making.

Neuroscience Links to the Humanities, Philosophy, and Psychology: Conscious and Unconscious Perception and Unconscious Instinctive Behavior

The unity of consciousness—our sense of self—is the greatest remaining mystery of the brain. As a philosophical concept, consciousness continues to defy consensus, but most people who study it think of it as different states in different contexts, not as a unitary function of mind. One of the most surprising insights to emerge from the modern study of states of consciousness is that Freud was right: unconscious mental processes pervade conscious thought; moreover, not all unconscious mental processes are the same. Freud (see Gay, 1995) initially defined the *instinctual unconscious* as a single entity consisting largely of the aggressive and erotic feelings, thoughts, urges, and memories that lie outside consciousness yet influence our behavior and our experience (for a modern discussion see Alberini et al., 2013). He later added the *preconscious unconscious* (now called the adaptive unconscious), which is part of the ego and processes information without our being aware of it.

Thus Freud appreciated that a great portion of our higher cognitive processing occurs unconsciously, without awareness and without the capacity to reflect. When we look at a person's face, we don't consciously analyze its features and say, ''Ah, yes, that's so-and-so.'' Recognition just comes to us. Similarly, we do not consciously form grammatical structures. It's all done unconsciously—we just speak. Recently, several psychoanalysts (Shevrin and Fritzler, 1968) and neuroscientists (Edelman, 1989, 2004; Koch, 2004; Damasio, 2012; Ramachandran, 2004; Shadlen and Kiani, 2011; Dehaene, 2014) have attempted to define different states of consciousness operationally, to make them amenable to experimentation. One approach has been outlined by Shadlen and Kiani (2011), who argue that awareness and subjective aspects of perception and volition are interrelated. They advance the idea that the neural mechanisms that give rise to conscious states share features with the neural mechanisms that underlie simpler forms of decision making, designed to engage with the environment.

Dehaene, who uses brain imaging to study a mental process that parallels the adaptive unconscious, takes another approach. He distinguishes a minimum of three states of consciousness: (1) the state of wakefulness—awakening from sleep; (2) the state of attention—processing a specific piece of information without necessarily being aware of it, such as feeling hungry or seeing a friend; and (3) the state of perceptual awareness (authorship) and reportable consciousness—becoming aware of some of the information we pay attention to and being able to tell others about it (Dehaene, 2014). The second state—attention—is a transitional state between wakefulness and reportable consciousness. Dehaene holds that our experience of consciousness is based on these three independent but overlapping states. The three states presumably reflect different biological processes, and since wakefulness is essential for both processing information and reportable consciousness, the processes presumably interact. Dehaene argues that only reportable consciousness corresponds to the idea of consciousness discussed by philosophers in the past.

The State of Wakefulness

Until relatively recently, wakefulness—arousal and vigilance—was considered to result from sensory input to the cerebral cortex: when sensory input is turned off, we fall asleep. In 1949 Giuseppe Moruzzi, an Italian scientist, and Horace Magoun, an American physiologist, found in experiments with animals that severing the neural circuits that run from the sensory systems to the brain in no way interferes with consciousness, the wakeful state; however, damaging a region of the upper brain stem known as the wakefulness center produces coma (Moruzzi and Magoun, 1949). Moreover, stimulating that region will awaken an animal from sleep. Moruzzi and Magoun thus discovered that the brain contains a neural system that carries the information necessary for the conscious state from the brain stem and midbrain to the thalamus, and from the thalamus to the cortex. Their work opened up the empirical study not only of consciousness and coma, but also of sleep, thus linking brain science and psychology to sleep and wakefulness.

Psychology Meets Neuroscience: The Global Workspace

In 1980 the cognitive psychologist Bernard Baars introduced the Global Workspace Theory. According to this theory, consciousness (attention and awareness) involves the widespread broadcasting of previously unconscious information throughout the brain (Baars, 1997). The global workspace comprises the system of neural circuits that transmits this information from the brain stem to the thalamus and from there to the cerebral cortex. Before Baars wrote *A Cognitive Theory of Consciousness* (Baars, 1988), the question of consciousness was not considered a scientifically worthy problem by most psychologists. We now realize that brain science has a number of techniques for examining consciousness in the laboratory. Basically, experimenters can take any one of a variety of stimuli, such as an image of a face or a word, change the conditions a bit, and make our perception of that stimulus come into and go out of consciousness at will. This biological approach to consciousness is based on a synthesis of the psychology of conscious perception and the brain science of neural circuits broadcasting information throughout the brain. The two are inseparable. Without a good psychology of the conscious state, we can't make progress in the biology, and without the biology we will never understand the underlying mechanism of consciousness. This is the new science of the mind in action.

Imaging the Global Neural Workspace

Dehaene extended Baars's psychological model to the brain (for earlier psychological studies using a paradigm similar to Dehaene's, see for example Shevrin and Fritzler, 1968). He found that what we experience and report as a conscious state is accompanied by activity in a set of widely distributed neural circuits; these circuits select a piece of information, amplify it, and broadcast it forward to the cortex. Baars's theory and Dehaene's findings show us that we have two different ways of thinking about things: one is an unconscious process; the other is conscious.

The major difficulty in trying to image aspects of consciousness in the brain has been to find experimental methods that would enable us to contrast unconscious and conscious processing. Dehaene found a way to do it. He flashes the words ''one,'' ''two,'' ''three,'' ''four'' on a screen. Even when he flashes them very quickly, you can see them. But when he flashes a shape just before and just after the last word, ''four,'' the word seems to disappear. The shape masks the word. The word is still there on the screen, it is still there on your retina, your brain is processing it—but you are not conscious of it. Going a bit further, Dehaene places the words just at the threshold of consciousness, so that half of the time you will say you saw them, and half of the time you will say you didn't see them. The objective reality of the words is exactly the same whether you think you saw them or not.

Dehaene then asked, ''What happens when we see a subliminal word?'' He found that first the visual cortex becomes very active. This is a correlate of unconscious activity: the word we have seen has reached the early visual processing station of the cerebral cortex. After 200 or 300 ms, however, the activity dies out without reaching the higher centers of the cortex. This was surprising. Thirty years ago, if asked whether an unconscious perception could reach the cerebral cortex, neuroscientists would have said no, only conscious information reaches the cortex.

Something quite different occurs when a perception becomes conscious and reportable, Dehaene found. Conscious perception also begins with activity in the visual cortex, but instead of dying out, the activity is amplified. After about 300 ms, it becomes very large, like a tsunami instead of a dying wave. It reaches higher into the brain, up to the prefrontal cortex. From there it goes back to where it started, creating reverberations. This is the broadcasting of information that occurs when we are conscious. It moves information, Dehaene argues, into the global workspace, where it can be accessed by neural functions in other regions of the brain. In psychological terms, what happens when we are conscious is that information becomes available in this larger system, which is detached from our perception of the actual word. The word is flashed only briefly, but we can keep it in mind with our working memory and broadcast it to all areas of the brain that need it. Thus, we can say that conscious information is globally broadcast information; it is globally available in the brain. This mechanism has proven to apply to other sensory stimuli as well. Since we can only focus our attention on one piece of sensory information at a time, Dehaene argues that reportable consciousness evolved to enable us to keep that information active and route it to other areas of the brain. These areas include the prefrontal cortex, which is involved in decision making; the temporal lobe, which is necessary for explicit memory; and the language areas involved in reporting conscious experiences, where they can be evaluated, memorized, or used to plan the future (Dehaene, 2014). As these arguments make clear, we have various forms of consciousness that play specific roles in our mental life. We are beginning to understand some aspects of the biological functions of these forms, as well as the biological necessity for them.

Biological Perspective on Consciousness Studies

The broadcasting of unconscious information to the global workspace represents some aspects of consciousness, but other aspects may not be that simple. In other words, not all of the information broadcast to the cortex in response to a sensory stimulus results in our becoming consciously aware of that stimulus. How do we distinguish between something that is correlated with conscious activity (the neural correlate of consciousness) and something that actually causes conscious activity? To prove that a state of the brain truly causes a state of mind, we need to perturb the brain and show that it changes the mind. Daniel Salzman and William Newsome of Stanford University (Salzman et al., 1992; Salzman and Newsome, 1994) have done this using electrical stimulation to manipulate the information-processing pathways in the brain of animals. The animals are asked whether dots on a screen are moving to the left or to the right. By stimulating just a tiny bit of the brain area that is concerned with visual movement, Salzman and Newsome can induce a slight change in the animals' perception of which way the dots are moving. This change in perception causes the animals to change their minds about which way the dots are moving. In parallel work, Logothetis and Schall (1989) have examined binocular rivalry, in which one image is presented to one eye and a very different image is presented to the other eye. Instead of the two images being superimposed, the viewer's perception flips from one image to the other. In their experiments, Logothetis and Schall train animals to "report" these flips. They found that some neurons respond only to the physical image, while others respond to the animal's perception of it. Their study has spawned other work, the gist of which is that the number of neurons attuned to percepts becomes greater as we move from the primary visual cortex to higher regions of the brain. These experiments explore some core aspects of the mind-brain problem. Although we are only beginning to study the biology of consciousness, we now have a few useful paradigms for exploring different states of consciousness.

Unconscious Mental Processes

The experiments described above demonstrate that information can enter our cortex yet not give rise to conscious perception. Intriguingly, however, such information *can* affect our behavior. Unconscious processing can take place simultaneously in many different areas of the cortex. The mere recognition of a word can occur unconsciously, while the meaning of that word can be accessed at much higher levels in the brain without our being aware of it. Other aspects of the word can also be computed unconsciously, such as its sound, its emotional content, or whether you spoke it in error and want to catch the error.

Ever since the nineteenth-century German physiologist and psychologist Hermann von Helmholtz first discovered unconscious processing, scientists have been struggling to understand how it works and how deep it can go (Meulders, 2010). von Helmholtz realized that the brain is creative: it automatically (unconsciously) assembles basic bits of information from the sensory systems and draws inferences from them. In fact, the brain can make complex inferences from very scant information. When you look at a series of black lines, for instance, the lines don't mean anything; but if the lines begin to move—and particularly if they move forward—your brain instantly recognizes them as a person walking. Helmholtz understood that the unconscious brain can take partial information, compare it to previous experience, and make a learned, rational judgment. This was an amazing insight.

In 1939 Heinz Hartmann dramatically expanded our understanding of Freud's preconscious unconscious in an essay entitled "Ego Psychology and the Problem of Adaptation" (Hartmann, 1964). He developed the idea that the ego has innate abilities, many of which are unconscious and facilitate our ability to adapt to the environment. Recently, scientists have recognized this higher level of unconscious thinking.

The Adaptive Unconscious

Timothy Wilson, a cognitive psychologist, has now expanded on Freud's and Hartmann's view and introduced the idea of the adaptive unconscious, a set of unconscious processes that serves a number of functions; one of them is decision making (see also Dijksterhuis and Nordgren, 2006). For many years, behavioral researchers have been trying to tease apart the conscious and unconscious components of our everyday judgments and decisions. They have documented that our mind has two ways of thinking: the slow, deliberate, conscious process and a faster, adaptive unconscious. While we consciously focus on what's happening around us, the adaptive unconscious lets part of our mind keep track of what's going on elsewhere, to make sure we aren't missing something important.

Many of us, when faced with an important choice, make a list of pluses and minuses to help us decide what to do. But experiments have shown that this may not be the best way to make a decision. Instead, we should gather as much information as possible unconsciously. A preference will bubble up. If we are overly conscious, we may talk ourselves into thinking that we prefer something we really don't. Sleeping helps equilibrate emotions, so when it comes to an important decision, we should literally sleep on it (see for example Nordgren et al., 2011).The adaptive unconscious is vital to our survival. It works in tandem with consciousness to guide us in ways that make us the smartest species on Earth. And since we have evolved two different kinds of mental processes to deal with different kinds of mental information, it would be interesting to see how far back they go in evolution.

Interplay of Conscious and Unconscious Mental Processes

As we will see in the discussions that follow, almost every mental function requires the interplay of conscious and unconscious processes. Thus, for example, the biology of conscious and unconscious processes could provide an important new link between psychoanalytic theory and the modern science of the mind. Such a link would enable us to explore, modify, and, where appropriate, disprove psychoanalytic theories about the unconscious. For its part, the new science of the mind might well be enriched by psychoanalytic ideas. Using Dehaene's operational approach, we might explore how Freud's instinctual unconscious maps onto modern biological insights into social behavior and aggression. Do these unconscious processes reach the cerebral cortex, even though they may not reach consciousness? What neural systems govern mechanisms of defense, such as sublimation, repression, and distortion?

Creativity has been described as the recruitment of unconscious thought and its ability to find new combinations and permutation of ideas. The description was formalized in the 1950s by Ernst Kris (Kris, 1952), an art historian and psychoanalyst. According to Kris, creative people have moments in which they experience, in a controlled fashion, a relatively unrestricted and easy communication between unconscious and conscious mental processes. He called this communication ''regression in the service of the ego.'' By regressing in a controlled manner, as opposed to the uncontrolled regression of a psychotic episode, an artist can bring the force of unconscious drives and desires into the forefront of his or her images. Cognitive psychological studies of creativity are generally consistent with Kris's view, but we know very little about the biology of creativity. Following the discovery that language is represented in the left hemisphere of the brain, John Hughlings Jackson, the founder of British neurology, argued that the left hemisphere is specialized for analytical organization, whereas the right hemisphere is specialized for associating stimuli and responses and thus for bringing new combinations of ideas into association with each another.

Recent studies by Jung-Beeman and Kounios (Jung-Beeman et al., 2004) are consistent with this idea. The researchers presented study participants with simple problems that could be solved either by a flash of insight or by systematic thought. Using brain imaging, Jung-Beeman and Kounios found that a region of the right temporal lobe, the anterior superior temporal sulcus, became particularly active when participants experienced a flash of insight. The same region was also active during their initial effort to solve the problem, which indicates that the creative insight may have enabled them to see connections between ideas. The evolving biology of conscious and unconscious mental processes will eventually influence many human endeavors, from mathematical thinking and computer science to creativity in arts and science, from evaluation of child-rearing practices to judgments of guilt and innocence in the courtroom, and from normal social behavior to disorders of behavior—many of which involve disorders of conscious and unconscious mental processes.

Emotion and the Instinctive Unconscious

Emotions are behaviors that are associated with internal (instinctive) states such as sex, aggression, and fear, all of which have important unconscious components, as Freud pointed out. Recently, we have gained new insights into the brain mechanisms that are responsible for behavioral states, including the paradox of sex and aggression. Usually, these two instinctive drives are mutually exclusive, but under some circumstances they reinforce each other, as we shall see. In the last several decades, neuroscience has opened new windows onto the molecular biology of social behavior. The resulting insights are likely to stimulate thinking in sociology and promise new approaches to understanding empathy, aggression, pair bonding, promiscuity, and other social issues.

The Nature of Social Affiliation

Cori Bargmann at Rockefeller University has shown that the two strains of the worm *C. elegans* forage for food in different ways (de Bono and Bargmann, 1998). Members of one strain are loners: they go out by themselves and gather bacteria, the source of their food. Members of the other strain forage collectively. Bargmann traced this difference in behavior to a variation in the gene that codes for a particular neuropeptide—specifically, to a difference in one amino acid. Eventually, Bargmann and her colleagues discovered that feeding behavior is controlled by a pair of neurons. These neurons collect information on the immediate environment that is funneled to them from various sensory neurons. When the environment is conducive to collective feeding, the neurons send ''let's get together'' signals to the animals' motor systems and muscles, and collective feeding is initiated. But when a particular variant of a particular gene is active, information about the environment cannot reach the neurons, and the animals remain solitary. These observations give us some insight into how a nervous system creates behavior—and that is our goal in studying the social brain.

Tom Insel, while at Emory University, discovered an even more dramatic difference in the behavior of two species of voles, a small rodent (Insel and Fernald, 2004). Prairie voles are highly social animals that form permanent pair-bonds. Montane voles, in contrast, are somewhat asocial but promiscuous in their mating. This difference in behavior is caused by a variation in the gene that codes for two particular peptides, oxytocin and vasopressin. Insel later inserted an oxytocin gene into asocial mice, resulting in increased social behavior. These peptides play a key role in mammalian reproductive and social behavior, including our own. For example, Thomas Baumgartner and his colleagues at the University of Zurich found that oxytocin squirted into a person's nose can enhance the sense of trust (Baumgartner et al., 2008). It does so by acting on the amygdala and the midbrain, two regions involved in fear, and the dorsal striatum, a region involved in behavioral feedback. Oxytocin appears to produce a different effect when administered to people with borderline personality disorder: it impedes trust and positive social behavior. Scientists have argued that the link between oxytocin and serotonin may be different in people with this disorder, who suffer from social anxiety and sensitivity to rejection because of early experiences with a parent, a genetic predisposition, or both (Bartz et al., 2011; Baumgartner et al., 2008).

Bargmann extended Insel's work by identifying an amazing signaling system in *C. elegans* that consists of one peptide, nematocin. Nematocin, which is biochemically related to oxytocin and vasopressin, disturbs not only the worms' reproductive behavior but simple sensory and motor behaviors as well. From a detailed analysis of *C. elegans*' behavior (Garrison et al., 2012; Emmons, 2012), Bargmann has concluded that oxytocin and vasopressin increase the coherence and coordinated execution of mating behavior in worms. These findings suggest that the brain has specific mechanisms designed to promote positive social behavior. These mechanisms—which appear in organisms separated by 600 million years of evolution—are remarkably well conserved. Moreover, manipulation of the mechanisms can have a profound influence on social behavior.

Robert Malenka of Stanford University and his colleagues have taken a fresh look at positive group behavior (Dölen et al., 2013). They point out that even though social behavior promotes group survival in species as diverse as worms, honeybees, and humans, it nevertheless costs the individual effort and energy. Social behavior must provide some reward to the individual organism, they reasoned: why else would it have been conserved through evolution? They tested their idea in mice and found that oxytocin modulates the release of serotonin into the nucleus accumbens. Serotonin, a chemical that promotes feelings of well-being, rewards the mice for positive social behavior. Thus, the reinforcement of positive social interaction in mice requires the coordinated activity of both oxytocin and serotonin.

Empathy: Mirror Neurons as Mediators of Social Behavior

Giacomo Rizzolatti and his colleagues at the University of Parma in Italy (Rizzolatti et al., 1996) discovered a network of neurons in motor areas of the cortex of monkeys that mirror the actions of others. These neurons respond similarly under two conditions: when a monkey is performing an action and when the monkey observes another monkey or a person performing the same action. More recently, scientists have speculated that these mirror neurons may explain some aspects of social behavior. If a person is squinting his eyes and clenching his jaw, we automatically sense that he must be feeling anger. If he smiles, we assume he is happy. By mirroring his actions—the squinting eyes and clenched jaw—in our own body, mirror neurons may enable us to empathize with him and, by extension, to gauge his intentions.

Aggression

Aggression, like social behavior and fear, has been with us since the dawn of time. It is highly conserved in evolution—nearly every animal is capable of violence—yet we understand much less about the anatomy of aggression than the anatomy of fear. Darwin believed it was possible to study aggression in animals, and in 1928 Walter Hess proved him right. Hess found that by electrically stimulating certain areas in the hypothalamus of cats, he could elicit attack behavior. David Anderson has returned to the question recently (2012), using modern optogenetic methods to study aggression in mice. He and his colleagues (Lin et al., 2011) have identified neurons in a region of the hypothalamus whose activity causes males to attack other males, females, and even inanimate objects. These neurons receive signals from the amygdala, which orchestrates aggression. Surprisingly, 20% of the neurons that are activated during attacks are also active during mating, and 20% of the neurons that are active during mating are also active during attacks. This finding suggests that the neurons responsible for these opposing social behaviors reside in the same region of the brain.

Aggression has also been studied in fruit flies. Edward Kravitz and his colleagues at Harvard have found that when flies grapple with each other over a patch of food, they behave like sumo wrestlers, pushing against each other to achieve dominance (Chen et al., 2002). In fact, scientists have bred unusually aggressive flies to produce a hyperaggressive strain. David Anderson and colleagues have identified a sexually dimorphic class of neurons in the fruit fly that controls aggressiveness in males, but not in females (D. Anderson, personal communication). These neurons express the neuropeptide Substance P (Tachykinin), which is thought to contribute to aggressiveness in people. Interestingly, more than 60 years ago the ethologist Nikolaas Tinbergen (1951) had observed that there exists a tension between sexual and aggressive instincts, and this led him to make the prescient prediction that aggression is located in the same region of the brain as that which controls mating behavior. In his recent work, Anderson has shown that there is an overlap of the neuroanatomical circuitries for aggression and mating in mice and he has proposed that such overlap may account for this tension. (Anderson, 2012; Lin et al., 2011). He has also suggested that some forms of pathological violence in people could reflect faulty circuit wiring of the human brain (see also Frith, 2013).

The environment affects aggression in fruit flies almost as much as genes do. A fly that is isolated at the pupa stage and raised to adulthood in a vial is much more aggressive than flies that have been housed in groups. This is true throughout the animal kingdom—isolation breeds aggressiveness. The environment can also act by influencing the expression of genes. A prime example of this effect can be seen in people who were abused as children. A mutation in the gene monoamine oxidase leads to an increase in the production of noradrenaline, a chemical that predisposes people to aggression. The effect of the mutation is much more pronounced in people who were exposed to trauma in childhood. Studies of hyperaggressive flies may one day yield insights into how genes control aggression and into the interaction between heredity and environment in producing aggression.

Neuroscience Links to the Social Sciences, Ethics, and Public Policy: Free Will, Delayed Gratification, Decision Making, and Personal Responsibility

Free Will and Personal Responsibility

The biological role of the unconscious in decision making was explored in a simple experiment by Benjamin Libet at the University of California, San Francisco. Hans Helmut Kornhuber, a German neurologist, had shown that when you initiate a voluntary movement, such as moving your hand, you produce a readiness potential, an electrical signal that can be detected on the surface of your skull. The readiness potential appears a split second before your actual movement. Libet carried this experiment a step further. He asked people to consciously "will" a movement and to note exactly when that willing occurred. He was sure it would occur before the readiness potential, the signal that activity had begun. What he found, to his surprise, was that it occurred substantially *after* the readiness potential. In fact, by averaging a number of trials, Libet could look into your brain and tell that you were about to move before you yourself were even aware of it. At first blush, this astonishing result suggests that you have unconsciously decided to move before being aware of having made the decision. In fact, however, the activity in your brain precedes the *decision* to move, not the movement itself. What Libet showed is that activity precedes awareness, just as it precedes every action we take. We therefore have to refine our thinking about the nature of brain activity.

Decision Making

In the 1970s Daniel Kahneman and the late Amos Tversky began to entertain the idea that intuitive thinking functions as an intermediate step between perception and reasoning. They explored how people make decisions and, in time, realized that unconscious errors of reasoning greatly distort our judgment and influence our behavior. Their work became part of the framework for the new field of behavioral economics, and in 2002 Kahneman was awarded the Nobel Prize in Economics. Tversky and Kahneman identified certain mental shortcuts that, while allowing for speedy action, can result in suboptimal judgments. For example, decision making is influenced by the way choices are described, or "framed." In framing, we weigh losses far more heavily than equivalent gains. If a patient needs surgery, for instance, he is far more likely to undergo the procedure if the surgeon says that 90% of patients survive perfectly well, as opposed to saying that 10% of patients die. The numbers are the same, but because people are averse to risk, they much prefer to hear that they have a high probability of living than that they have a low probability of dying.

The issues of framing, bias, and rational decision making are being explored with brain imaging by Raymond Dolan and his colleagues (De Martino et al., 2006). They found that framing is associated with activity in the amygdala, suggesting that emotion plays a key role in decision bias. Moreover, activity in the prefrontal cortex generally predicts less susceptibility to the effects of framing. Kahneman and Tversky hold that there are two general systems of thought. System 1 is largely unconscious, fast, automatic, and intuitive—like the adaptive unconscious, or what Walter Mischel, a leading cognitive psychologist, calls "hot" thinking. In general, system 1 uses association and metaphor to produce a quick rough draft of an answer to a problem or situation. Kahneman argues that some of our most highly skilled activities require large doses of intuition: playing chess at a Masters level or appreciating social situations. But intuition is prone to biases and errors. System 2, in contrast, is consciousness-based, slow, deliberate, and analytical, like Mischel's "cool" thinking. System 2 evaluates a situation using explicit beliefs and a reasoned evaluation of alternatives. Kahneman argues that we identify with system 2, the conscious, reasoning self that makes choices and decides what to think about and what to do, whereas actually our lives are guided by system 1.

Systems Biology of Decision Making

A clear example of the systems biology of decision making has emerged from the study of unconscious emotion and conscious feeling and their bodily expression. Until the end of the nineteenth century, emotion was thought to result from a particular sequence of events: a person recognizes a frightening situation; that recognition produces a conscious experience of fear in the cerebral cortex; and the fear induces unconscious changes in the body's autonomic nervous system, leading to increased heart rate, constricted blood vessels, increased blood pressure, and moist palms. In 1884 William James turned this sequence of events on its ear. James realized not only that the brain communicates with the body but, of equal importance, that the body communicates with the brain. He proposed that our conscious experience of emotion takes places *after* the body's physiological response. Thus, when we encounter a bear sitting in the middle of our path we do not consciously evaluate the bear's ferocity and then feel afraid—we instinctively run away from it and only later experience conscious fear. The development of functional brain imaging in the 1990s confirmed James' theory. Using brain imaging, three independent research groups (Damasio, 2012; Craig, 2009; Critchley et al., 2004) discovered the anterior insular cortex, or insula, a little island in the cortex located between the parietal and temporal lobes. The insula is where our feelings are represented, our conscious awareness of the body's response to emotionally charged stimuli. The insula not only evaluates and integrates the emotional or motivational importance of these stimuli, it also coordinates external sensory information and our internal motivational states. This consciousness of bodily states is a measure of our emotional awareness of self, the feeling that "I am."

Joseph LeDoux, a pioneer in the neurobiology of emotion, found that the amygdala orchestrates emotion through its connections with other regions of the brain (Ledoux, 1996). A stimulus takes one of two routes to the amygdala. The first is a rapid, direct pathway that processes unconscious sensory data and automatically links the sensory aspects of an event together. The second pathway sends information through several relays in the cerebral cortex, including the insula, and may contribute to the conscious processing of information. LeDoux argues that together, the direct and indirect pathways mediate both the immediate, unconscious response to a situation and the later, conscious elaboration of it. With these studies, we are now in a position to go beneath the surface of mental life and begin to examine how conscious and unconscious experiences are related. In fact, some of the most fascinating recent insights into consciousness have come from studies that parallel James' thinking and examine consciousness through its role in other processes. Imaging studies by Wimmer and Shohamy (2012), for instance, show that just as the amygdala processes fear unconsciously and consciously through separate pathways, the same mechanisms in the hippocampus that are involved in the conscious recall of explicit memory can also guide and bias unconscious decisions (D. Shohamy, personal communication).

The Cell Biology of Decision Making

Following on the realization that biology is involved in decision making and choice, neurobiology began to interact with economics. Newsome and others are applying economic models to their experiments on the cellular level in an effort to understand the rules that govern decision making, while economists are interested in incorporating the outcome of those studies into their theories of economics. Neuroscientists are also making good progress in studies of decision making by examining single nerve cells in primates. A key finding, epitomized by the work of Shadlen, is that neurons in the association areas of the cortex, which are involved in decision making, have very different response properties than neurons in the sensory areas of the cortex. Sensory neurons respond to a current stimulus, whereas association neurons are active longer, presumably because they are part of the mechanism that links perception with a provisional plan for action. Shadlen's results indicate that association neurons accurately track the probabilities related to making a choice. For example, as a monkey sees more and more evidence indicating that a rightward target will dispense a reward, the neural activity that favors a rightward choice increases. This allows the monkey to accumulate evidence and make a choice when the probability of being correct passes some threshold, say 90%. The neurons' activity and the decision they drive can occur very rapidly—often in less than a second. Thus, under the right circumstances, even rapid decisions can be made in nearly optimal fashion. This may explain why the fast, unconscious, system 1 mode of thinking has survived: it may be prone to error under some circumstances, but it is highly adaptive under others.

Child Development and the Ability to Delay Gratification

Resisting temptation in favor of long-term goals is an essential component of social and cognitive development and of social and economic gain. In a classic series of experiments in the 1960s and 1970s, Mischel set out to demonstrate the processes that underlie self-control in preschool children (Mischel et al., 2011). Four- and five-year-old children were given a treat and told that if they waited a few minutes before eating it, they could have a second treat. Each child waited in a bare room, with no toys, books, or other distractions. Mischel's experiment allowed him to examine how the mental representation of the object of desire—that is, the mental image of two treats—enabled a young child to wait 15 min in a barren room. But the most profound result of his experiment was the strong correlation between the amount of time a child could wait and how that child fared later in life. By the time they reached age 16 or 17, the children who could delay gratification had higher scores on the SAT test than the children who could not wait, and they had greater social and cognitive competence in adolescence, as rated by their parents and teachers. At age 32, those who had delayed gratification were less likely to be obese, to use cocaine or other drugs, and so on.

Mischel also found he could teach children who could not delay gratification how to improve. One of the simplest ways was for the children to distract themselves from the object of desire: a sort of "Get thee behind me, Satan" strategy. Another way was for the child to pretend that the treat was just a picture: "Put a frame around it in your head," Mischel urged. This finding suggests that we might be able to help children learn how to delay gratification and then explore whether those early training experiences affect later performance on the SAT, the tendency to use drugs, and so on.

In recent brain-imaging experiments carried out with B.J. Casey, Mischel examined the original study participants and found that the children who had a greater ability to delay gratification had maintained that ability over 4 decades. The brains of these middle-aged adults showed greater activity in prefrontal cortex areas concerned with judgment, choice, and inhibition, whereas those who showed less ability to delay gratification had increased activity in the ventral striatum, which is linked to desire, reward, and addiction (Casey et al., 2011).

Personal Responsibility and the Courtroom

DNA evidence has been in forensic use for decades. It was first used in paternity cases to identify children's fathers. Then, in 1986, police in England asked Alec Jeffreys, a molecular biologist, to use DNA evidence to evaluate the testimony of a 17-year-old boy charged with raping and murdering two women. The DNA evidence established the boy's innocence and was later used to convict the actual murderer. Following this impressive beginning, DNA evidence underwent further extensive scrutiny in the courtroom and is now generally admissible in establishing guilt or innocence.

Today, there is great interest in using brain-based evidence in criminal proceedings, with neuroscientists acting as expert witnesses. This role is both important and problematic (for review, see Jones et al., 2013). Brain imaging was first introduced into the courtroom in 2006 in the case of Brian Dugan and has since been used in over 30 cases. Dugan, then 52 years old, was tried for the kidnapping and murder of a 10-year-old girl. His lawyer used brain imaging to show that Dugan had an injury that caused him to act psychopathically. (Psychopaths do not exhibit increased activity in two particular regions of the cortex when showed photographs of a moral violation; rather, they show decreased activity.) Experts testified for and against the validity of using brain imagining as evidence of culpability in such a case. Ultimately, the jury voted unanimously for a death sentence.

Similar issues of validity have arisen in regard to memory. The legal system has been slow to adopt research findings from cognitive psychological and neurological studies that question not only the reliability of eyewitness testimony but also the memory of jurors. We now realize that memory is a reconstructive process. It is susceptible to distortion and can be quite flawed (Lacy and Stark, 2013). This has profound implications for how much weight we must give eyewitness testimony in court, where even minor memory distortion can have severe consequences. In one experiment, for example, subjects mistakenly misidentified an individual as having committed a minor (staged) crime, when in fact they had only seen that individual later, during the (staged) investigation.

Alan Alda, the noted actor, explored the role of brain science in the courtroom for a PBS television program called ''Brains on Trial.'' In the course of his work he spoke extensively with neuroscientists, lawyers, and judges and came away with two very strong impressions. The first is that the new science of the mind and its insights into brain function are generating a lot of interest in the justice system, including the U.S. Supreme Court. Attorneys are very interested in the fact that we can look into a brain while it is recognizing a face, remembering a place, or experiencing an emotion. As a result, some of them are saying to themselves, ''Well, why don't we put the accused into an imaging machine and see if he really feels remorse, or if he is just saying he feels remorse?'' In fact, at least two companies claim that they can use an MRI machine as a lie detector. Alda's other strong impression is that scientists are very reluctant to use imaging as evidence in a courtroom. The MRI is a relatively crude measure of activity in whole areas of the brain, often on a relatively crude spatial scale and almost invariably on a crude temporal scale. The underlying mechanisms of brain activity—what little we know about them—turn out to be far more diverse than we originally thought. Moreover, many imaging studies do not base their findings on individual brains; they are an average of many people's brains. For all these reasons, it is not possible to look at activity in a person's brain and see what he or she is thinking.

Neuroscience as a forensic tool is in its infancy, but we can imagine a time when some brain-based information will help make decisions in the courtroom. For instance, some neurological or psychiatric conditions may result in a brain that cannot learn via the normal mechanisms of social reward and punishment. Neuroscience might therefore be helpful in determining when punishment for a criminal deed is an appropriate and effective solution and when it is not. While brain science may never be in a position to assign responsibility or to determine guilt or innocence, it may allow us to evaluate impulsiveness. That is, we cannot tell whether someone is lying or telling the truth, but we can gauge the degree of culpability or the likelihood of reliability. This raises an even deeper question: Does explaining behavior in neurological terms diminish culpability? Often, people worry that explaining unacceptable behavior tends to excuse it. However, most authors who have considered this subject agree that the impact of an explanation depends on the nature of the explanation. Thus, explaining the neural underpinnings of epilepsy would tend to excuse actions committed during a seizure, but explaining the neural underpinnings of greed would not excuse theft.

Neuroscience Links to the Perception of Art: The Beholder's Share

Brain science is likely to deepen our understanding of how we enjoy music, literature, and visual art, and perhaps even how we produce it. In turn, brain science will change as a result of its involvement with the perception and creation of art. Understanding how our sensory systems process information is one aspect of this change. A more complex one is understanding our aesthetic response to art. In this Perspective I consider only visual art. Thus the aesthetic question becomes, ''Why do two people look at the same image and one finds it beautiful while the other finds it boring?'' What is the nature of the beholder's response? Conceivably, the answers to these questions could give us a handle on the basis of creativity as well.

The first person to attempt to connect art and science was Alois Riegl (Riegl, 2000; Kemp, 2000), head of the Vienna School of Art History and one of the most important art historians of Vienna in 1900. Riegl emphasized an important psychological aspect of art that we now consider obvious: namely, that art is incomplete without the perceptual and emotional involvement of the viewer. Not only does the viewer collaborate with the artist in transforming a 2D image on a canvas into a 3D depiction of the visual world, the viewer also interprets what he or she sees on the canvas in personal terms, thereby adding meaning to the picture. Riegl called this phenomenon the beholder's involvement.

The idea that art is not art without the viewer's direct involvement was elaborated by the next generation of Viennese art historians, Ernst Kris and Ernst Gombrich (Kris, 1952; Gombrich, 1960, 1982). Drawing on ideas derived from Riegl and from contemporary schools of perceptual and Gestalt psychology, Kris and Gombrich devised a new approach to visual perception and emotional response, and they incorporated that approach into art criticism. Gombrich elaborated on Riegl's idea of the beholder's involvement and called it the beholder's share. Kris argued that when an artist produces a powerful image out of his own life experiences, the image is inherently ambiguous. That ambiguity, in turn, elicits unconscious processes of recognition in the viewer, who responds emotionally and empathically to the image in terms of his or her own life experience. Thus, the viewer undergoes a creative experience that, in a modest way, parallels the artist's own. Kris, and subsequently Gombrich, intuited and elaborated on the idea of the brain as a creativity machine. Gombrich realized that visual perception is only a special case of a larger philosophical question: How can the real world of physical objects be known through our senses (Berkeley, 1709; Gombrich, 1960, 1982)? The central problem of vision is that we cannot know the material objects of the world per se, only the light reflected off them. As a result, the 2D image projected onto our retina can never specify an actual 3D object. This fact, and the difficulty it raises for understanding our perception of any image, is referred to as the inverse optics problem (Albright, 2012; Purves and Lotto, 2010).

Even though there is not enough information in the image that our eyes receive to reconstruct an object accurately, we do it all the time. Clearly, our visual system must have evolved primarily to solve this fundamental problem. How do we do it? von Helmholtz argued that we solve the inverse optics problem by including two additional sources of information: bottom-up and top-down information (see also Adelson, 1993). Bottom-up information is supplied by computations that are inherent in the circuitry of our brain—we are born with them—and that enable us to extract key elements of images in the physical world, such as contours and junctions. These computations are governed by a set of universal rules that have evolved from natural selection. As a result, even children as young as 1–2 years can interpret images. Top-down information, in contrast, is supplied by learning: the individual experiences, memories, and associations that we bring to bear on every image, including a work of art.

Contemporary students of the inverse optics problem, Yasushi Miyashita et al. (1998), Thomas Albright (2012), and

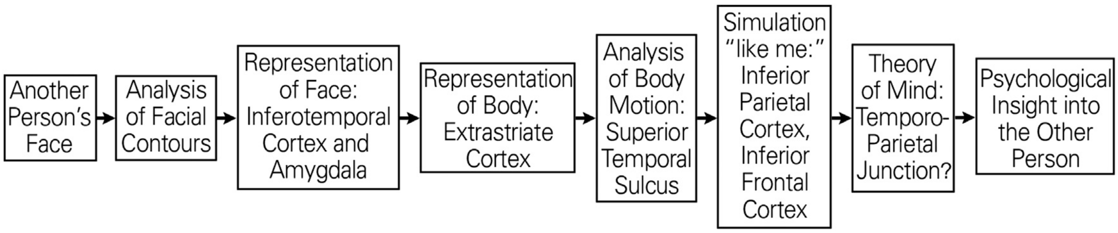

Figure 1. Flow Diagram of the Neural Circuit Involved in the Beholder's Share (Kandel, 2012)

Charles Gilbert (2012), have found that top-down processing activates particular neurons in the visual cortex and the medial temporal lobe, thus creating a neural correlate of an image. Under most conditions, the neural correlate resolves ambiguities in the bottom-up signal and fills in missing information. As we have seen, our brain does this largely unconsciously, on the basis of probability. Thus, we see what is likely to be out there in the world.

The Beholder's Share and Face Recognition

As we look at a person, our brain is busy analyzing facial contours, forming a representation of the face in our brain, analyzing the body's motion, forming a representation of the body, experiencing empathy, and forming a theory of the person's mind. These are all components of the beholder's share, and modern biology makes it possible for us to begin to explore them. Figure 1 shows an initial, extremely simple approximation of the neural circuit involved in the beholder's share. It indicates seven points of analysis along the circuit, as well as the components of the beholder's share and some of the areas of the brain involved in each. Analysis of facial contours and the brain's representation of a face are clearly of central importance to the beholder's share. Fortunately, we have learned a great deal about the psychology of face recognition and the biological processes underlying it.

The Psychology of Face Recognition

Our brain is specialized to deal with faces. Indeed, face perception has evolved to occupy more space in our brain than any other figural representation. As Darwin pointed out, the face and the emotion it conveys are involved in nearly all human interactions (Darwin 1871, 1872). We judge whether we trust people or are scared of them in part by the facial expressions they show us when we interact with them (Ekman, 1989). We are attracted to people, of the same sex and the opposite sex, because of their physical appearance and their facial expressions. We elect people to public office based on assessments about their competence that we infer from their faces (Todorov et al., 2005).

Face recognition is a difficult task for computers, but we can recognize hundreds of faces effortlessly. Why? Because the brain treats faces very differently from other objects. For one thing, face recognition is uniquely sensitive to inversion. If we were to turn a bottle of water upside down, we would still recognize it as a bottle of water. However, we might not recognize a face when it is upside down. Giuseppe Arcimboldo, a sixteenth-century Milanese artist, illustrates this dramatically by using fruits and vegetables to create faces in his paintings (see also Kandel, 2012). When we view the paintings right-side up, we readily recognize faces, but when the paintings are inverted, we typically recognize only bowls of fruits and vegetables (Figure 2).

Not only do we have difficulty recognizing an inverted face, we cannot under most circumstances recognize a change in expression on an inverted face. If we view two images of the *Mona Lisa* upside down (Figure 3), we may recognize both of them as the Mona Lisa but not realize that they have different expressions (Figure 4). With an object other than a face, we would have spotted the difference (Thompson, 1980).

Biology and the Representation of Faces in the Brain

Scientists have learned an enormous amount about the representation of faces in the brain from people who have face blindness, or prosopagnosia. This condition results from damage to the inferior temporal cortex, whether acquired or congenital. About 10% of people have a modest degree of face blindness. People with damage in the front of the inferior temporal cortex can recognize a face as a face but cannot tell whose face it is. People with damage to the back of the inferior temporal cortex cannot see a face at all.

Studies in animals have also contributed to our understanding of face recognition (Kobatake and Tanaka, 1994; Tsao et al., 2008; Tsao and Livingstone, 2008). Figure 5 shows how a cell in a monkey's "face patch"—a region of the brain that is specialized for face recognition—responds to various images. Not surprisingly, the cell fires very nicely when the monkey is shown a picture of another monkey (Figure 5A). The cell fires even more dramatically in response to a cartoon face (Figure 5B): monkeys, like people, respond more powerfully to cartoons than to real objects because the features in a cartoon are exaggerated. But a face has to be complete in order to elicit a response. When the monkey is shown two eyes in a circle (Figure 5C), there is no response. A mouth and no eyes elicits no response (Figure 5D). There is also no response when the surrounding circle is replaced with a square (Figure 5E). If shown only a circle, there is no response either (Figure 5F). The cell only responds to two eyes and a mouth inside a circle (Figure 5G). If the circles and the mouth are only outlined, there is no longer a response (Figure 5H). In addition, if the monkey is shown an inverted face, the cell does not respond (not shown).

Computer models of vision suggest that some facial features are defined by contrast (Sinha et al., 2006). Eyes, for example, tend to be darker than the forehead, regardless of lighting conditions. Moreover, such contrast-defined features may signal the brain that a face is present. To test these ideas in the cells of the monkey's face patch, Shay Ohayon, Freiwald, and Tsao

Figure 2. Giuseppe Arcimboldo, *The Vegetable Gardener*, 1587–1590
14.1 × 9.4 inches, oil on panel. Museo Civico Ala Ponzone, Cremona, Italy.

Figure 3. Inverted Images of da Vinci's *Mona Lisa*
Adapted from Thomas, P. (1980). ''Margaret Thatcher: A New Illusion.'' Perception, 9: 483–484. p. 483, Figure 1.

(Ohayon et al., 2012) presented monkeys with a series of artificial faces, each of whose features was assigned a unique luminous value ranging from dark to bright. They then recorded the activity of individual cells in the face patches in response to the artificial faces and found that the cells do indeed respond to contrasts between facial features. Ohayon and his colleagues later studied the cells' response to images of real faces and found that, again, responses increased with the number of contrast-defined features. Tsao, Freiwald, and their colleagues had found earlier that cells in the face patches respond selectively to the shape of some facial features, such as noses and eyes (Tsao et al., 2008). Ohayon's findings now showed that this selective response depends on luminance relative to other parts of the face. Most of the cells they studied respond both to contrast and to the shape of facial features, which leads us to an important conclusion: contrast is useful for face detection, and shape is useful for face recognition. These studies have shed new light on the nature of the templates the brain uses to detect faces. Behavioral studies suggest a powerful link between the brain's face detection machinery and the areas of the brain that control attention, which may account for why faces—and particularly portraits—draw our attention so strongly.

Neuroscience Links to Disorders of Mind: Psychiatry, Psychoanalysis, and Psychotherapy

When psychoanalysis emerged from Vienna early in the twentieth century, it represented a revolutionary way of thinking about the human mind and its disorders. The excitement surrounding the theory of unconscious mental processes increased as psychoanalysis was brought to the United States by immigrants from Germany and Austria. Under the influence of psychoanalysis, psychiatry was transformed in the decades following World War II from an experimental medical discipline closely related to neurology into a nonempirical specialty focused on psychotherapy. In the 1950s academic psychiatry abandoned some of its roots in biology and experimental medicine and gradually became a therapeutic discipline based on psychoanalytic theory. Over the next 50 years, psychoanalysis exhausted much of its novel investigative power. It also failed to submit its assumptions to the sort of rigorous tests that are needed to inspire confidence. Indeed, it was far better at generating ideas than at testing them. Fortunately, some people in the psychoanalytic community thought that empirical research was essential to the future of the discipline. Because of them, two trends have gained momentum in the last several decades. One is the insistence on evidence-based psychotherapy; the other is an effort to align psychoanalysis with the emerging biology of mind.

Perhaps the most important driving force for evidence-based therapy has been Aaron Beck, a psychoanalyst at the University

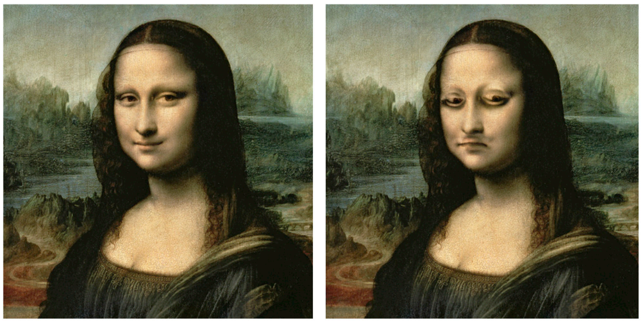

Figure 4. Upright Images of da Vinci's *Mona Lisa*
Adapted from Thomas, P. (1980). "Margaret Thatcher: A New Illusion." Perception, 9: 483–484. p. 483, Figure 2.

of Pennsylvania. Whereas traditional psychoanalysis teaches that mental problems arise from unconscious conflicts, Beck became convinced that conscious thought processes also play a role in mental disorders. Beck found that cognitive style—a person's way of perceiving, representing, and thinking about the world—is a key element in a number of disorders, including depression, anxiety disorders, and obsessive-compulsive states. He found that his depressed patients had a systematic negative bias. They almost invariably had unrealistically high expectations of themselves, put themselves down whenever possible, and were pessimistic about their future. Beck addressed these distorted negative beliefs and found that his patients often improved with remarkable speed, feeling and functioning better after a few sessions. This led him to develop cognitive behavioral therapy, a systematic approach to therapy that focuses on the patient's cognitive style and distorted way of thinking (Beck, 1995).

This systematic approach enabled Beck and others to study the outcomes of treatments for depression empirically. Their studies showed that cognitive behavioral therapy is as effective as, or more effective than, antidepressant medication in treating people with mild and moderate depression. It is less effective in severe depression, but it acts synergistically with antidepressants. Beck's findings encouraged investigators to carry out empirical outcome studies of psychoanalytically oriented insight therapy, and some progress has been made in this area (Roose et al., 2008; Shedler, 2010). In fact, a modest movement is now afoot to develop biological means of testing specific aspects of psychoanalytic theory and thus to link psychoanalysis to the biology of the mind.

One reason we know so little about the biology of mental illness is that we know little about the neural circuits that are disturbed in psychiatric disorders; however, we are now beginning to discern a complex neural circuit that becomes disordered in depressive illnesses. Helen Mayberg, at Emory University, and other scientists have used brain-scanning techniques to identify several components of this circuit, two of which are particularly important. One is Area 25 (the subcallosal cingulate region), which mediates our autonomic and motor responses to emotional stress; the other is the right anterior insula, a region that becomes active during tasks that involve self-awareness as well as tasks that involve interpersonal experience. These two regions connect to other important regions of the brain, all of which can be disturbed in depressive illness. In a recent study of people with depression, Mayberg gave each person either cognitive behavioral therapy or an antidepressant medication (McGrath et al., 2013). She found that people who started with less than average activity in the right anterior insula responded well to cognitive behavioral therapy but not to the antidepressant. People with greater than average baseline activity responded to the antidepressant but not to cognitive behavioral therapy. Mayberg could actually predict a depressed person's response to specific treatments from the baseline activity in their right anterior insula. Although we need to figure out what causes this differential baseline activity, the results show us several important things about mental disorders. First, the neural circuits that are disturbed are likely to be very complex. Second, we can identify specific, measurable biological markers of a mental disorder, and those biomarkers can predict the outcome of two different treatments: psychotherapy and medication. Third, psychotherapy is a biological treatment, a brain therapy. It produces physical changes that can be detected with brain imaging.

Genetics and Disorders of Mind

Any discussion of the biological basis of psychiatric disorders must include genetics. We are beginning to fit new pieces into the puzzle of how genetic mutations influence brain development. Two recent findings are particularly important. Most mutations produce small differences in our genes, but scientists have recently discovered that some mutations give rise to structural differences in our chromosomes. Such differences are known as copy number variations. People with copy number variations may be missing a small piece of DNA from a chromosome, or they may have an extra piece of that DNA. Matthew State now at the University of California, San Francisco, has discovered a remarkable copy number variation involving chromosome 7 (Sanders et al., 2011). An extra copy of a particular segment of this chromosome greatly increases the risk of autism, which is characterized by social isolation. Yet the loss of that same segment results in Williams Syndrome, a disorder characterized by intense sociability. This single segment of chromosome 7 contains about 25 of the 21,000 or so genes in our genome, yet an extra copy or a missing copy has profound, and radically different, effects on social behavior.

The second new genetic finding is de novo point mutations. These mutations arise spontaneously in the sperm of adult men. Thus, a father can transmit a de novo point mutation to one child without transmitting it to his other children or having the mutation himself. Sperm divide every 15 days. This continuous division and copying of DNA leads to errors, and the rate of error increases significantly with age: a 20-year-old man will have an average of 25 de novo point mutations in his sperm, whereas a 40-year-old man will have 65. These mutations are one of the reasons that older fathers are more likely to have children with autism. Older fathers are also at greater risk of having children with schizophrenia. Gulsuner and his colleagues identified 50 specific de novo mutations that occur in children who develop schizophrenia but whose parents do not have the disease (Gulsuner et al., 2013). They then tracked those 50 mutant genes to their locations on normal brain tissue ranging in age

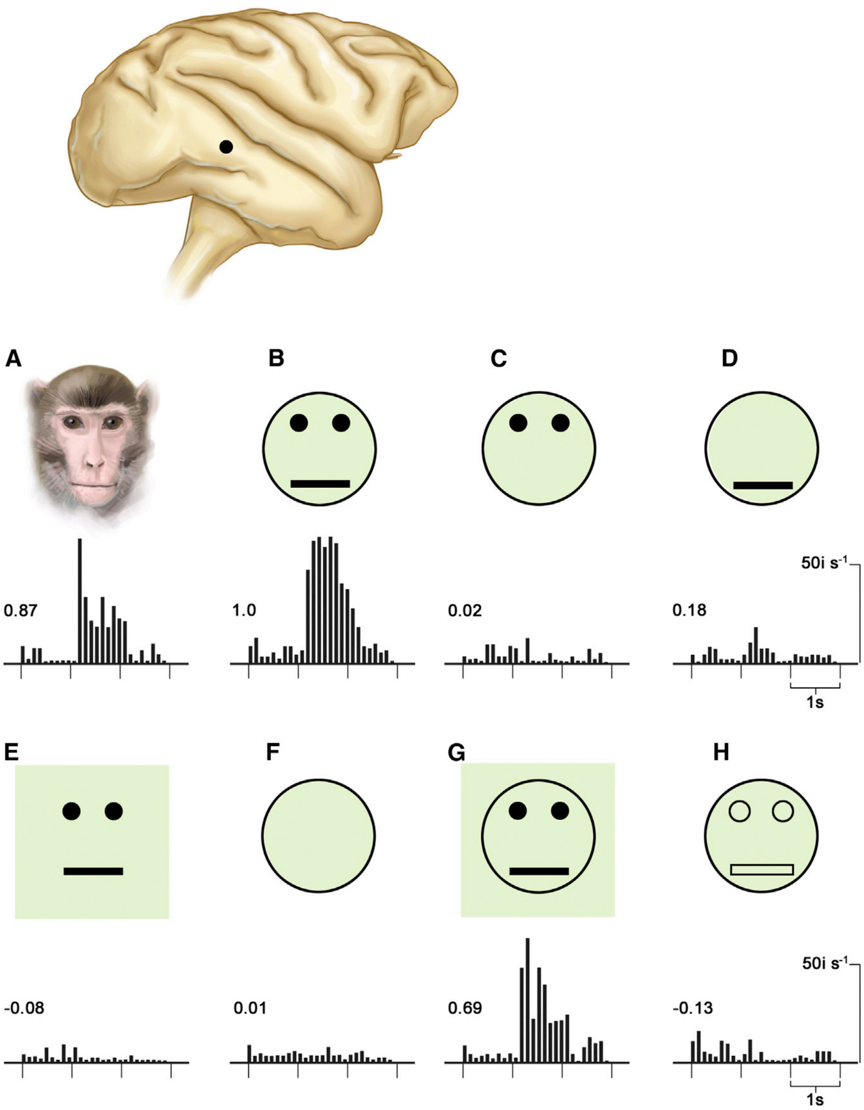

Figure 5. Using a Visual Stimulus to Excite a Single Cell in the Macaque Face Patch
Adapted from Kobatake, E., and Tanaka, K. (1994). "Neuronal selectivities to complex object features in the ventral visual pathway of the macaque cerebral cortex." J. Neurophysiol. 71, 856–2280. p. 859, Figure 4.

from 13 weeks of gestation to adulthood. They found that the genes form a network in the areas of the prefrontal cortex that are involved in judgment and working memory. The network influences three essential brain functions—the migration of neurons during development, synaptic transmission, and the regulation of gene transcription. This finding strengthens the idea that genetic disruption of neurogenesis in the prefrontal cortex is critical in the development of schizophrenia. These advances in genetics research show us that mental disorders are biological in nature and that our individual biology and genetics contribute significantly to the development of them. Ultimately, we need to understand how biological factors interact with the environment to produce mental disorders.

Knowing Ourselves: A New Dialogue between Brain Science, the Social Sciences, and the Humanities

Establishing and maintaining a dialog that includes brain science, the social sciences, and the humanities will not be easy. Important insights into the mind have come from writers and poets as well as from philosophers, psychologists, scientists, and artists. Each kind of creative endeavor has made and will continue to make contributions to our conception of the mind. If we disregard one in favor of another, that conception will be incomplete. Some humanists worry that biological analysis will diminish our fascination with mental activity or will trivialize important issues. It is my strong belief that scientific contributions to the humanities will not trivialize the mind, but rather will illuminate some of the most difficult questions about complex mental processes. When we explain the machinery of the brain, we don't explain away creativity. Nor do we explain away choice, volition, or responsibility. Some worries are legitimate. Science that is done badly or is interpreted uncritically can trivialize both the brain and whatever aspect of life it is trying to explain. Attributing love simply to extra blood flow in a particular part of the brain trivializes both love and the brain. But if we could understand the various aspects of love more fully by seeing how they are manifested in the brain and how they develop over time, then our scientific insights would enrich our understanding of both the brain and love.

Scientific analysis represents a move toward greater objectivity, a closer description of the actual nature of things. In the case of visual art, science describes the observer's view of an object not only in terms of the subjective impressions it makes on the senses, but also in terms of the brain's physical mediation of that impression. Art complements and enriches the science of the mind. Neither approach can describe human experience fully. What we require is interaction that encourages new ways of thought, new directions, and new experimental approaches in both art and the biology of the mind.

The relationships between psychology and brain science or between art and the new science of the mind are evolving. We have seen how the insights and methods of psychology have been challenged—and often ratified—by brain science and how expanded knowledge of brain function has benefited the study of behavior. We have seen that our perception and enjoyment of art is wholly mediated by the activity of our brains, and we have examined a number of ways in which insights from brain science enrich our discussion of art. We have also seen how much brain science can gain from trying to explain the beholder's share.

Any grand vision of the unity of knowledge must be met with a strong dose of historical reality. The gap that began to emerge between the sciences and the humanities in the last century, first described by C.P. Snow in his famous 1959 lecture ''The Two Cultures,'' has not disappeared—and it is not likely to disappear as an inevitable outcome of progress. Rather, we should approach the ideal of unity by opening discussions between restricted areas of knowledge. Dialogues are most likely to be successful when fields of study are naturally allied, as are the biology of the mind and the perception of art, and when the goals of the dialog are limited and benefit all of the fields that contribute to it. It is very unlikely that a complete unification of aesthetics and the biology of the mind will occur in the foreseeable future, but it is quite likely that a new dialog between, say, aspects of art and aspects of the science of perception and emotion will continue to enlighten both fields and that in time the dialog may well have cumulative effects.

The potential benefits for the new science of the mind are obvious. One is that contact with disciplines in the humanities is likely to yield new insights into the variety and purposes of conscious and unconscious mental processes. Another benefit is to understand how the brain responds to works of art, or how we process unconscious and conscious perception, emotion, and empathy. How might this dialog benefit artists? Since the beginning of modern experimental science in the fifteenth and sixteenth centuries, artists—from Filippo Brunelleschi and Masaccio to Albrecht Dürer and Pieter Bruegel to Richard Serra and Damien Hirst—have been interested in science. Leonardo da Vinci used his knowledge of anatomy to depict the human form more compellingly and accurately than any artist before him. So, too, contemporary artists may use our understanding of the biology of perception and of emotional and empathic response to create new art forms and other expressions of creativity.

Thus, for the first time we are in a position to address directly what neuroscientists can learn from the experiments of artists and what artists and beholders can learn from neuroscience about artistic creativity, ambiguity, and the perceptual and emotional response of the viewer. Some artists who are intrigued by the irrational workings of the mind, such as René Magritte and other surrealists, have already created a new art form, relying on introspection to infer what was happening in their own minds. While introspection is helpful and necessary, it cannot provide a detailed understanding of the brain and its workings. Artists today can enhance traditional introspection with a knowledge of how aspects of our mind work.

We have seen in this essay four specific areas in which the new science of the mind is particularly well positioned to enrich our understanding of other areas of knowledge. We have seen its potential as an intellectual force and a font of new knowledge that is likely to bring about a new dialog between the natural sciences, the social sciences, and the humanities. This dialog could help us understand better the mechanisms in the brain that make creativity possible, whether in art, the sciences, or the humanities, and thus open up a new dimension in intellectual history. In addition, an enriched understanding of the brain is needed to guide public policy. Particularly promising areas are the cognitive and emotional development of infants, the improvement of teaching methods, and the evaluation of decisions. But perhaps the greatest consequence for public policy is the impact that brain science and its engagement with other disciplines is likely to have on the structure of the social universe as we know it.

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