CHAPTER ONE

The Nature of Intelligence

In the now classic tale, three blind men approached an elephant and were curious about its nature. Having never encountered an elephant before, the men each had a different impression. For the man holding the elephant's thick legs, the elephant was like a tree. The elephant was snakelike to the man who had the elephant's lively trunk in his hands. The third blind man, feeling the elephant's sturdy side, exclaimed it was like a wall.

Who was right? And what does this story have to do with intelligence? Just like the blind men in our story, people exploring the nature of intelligence cannot see the object of their study and so have used metaphors to help them conceptualize intelligent behavior (Sternberg, 1990). In this chapter we describe some of the earliest notions of intelligence, which predate scientific study by hundreds, even thousands, of years. Next we present seven metaphors that underlie modern intelligence research: geographic, computational, biological, epistemological, sociological, anthropological, and systems. We briefly describe each metaphor, highlighting the major theories of intelligence associated with each one.

The first people to ponder the nature of intelligence were not psychologists or educators, but philosophers. The ancient-Greek philosopher Plato likened people's intelligence to blocks of wax, differing in size, hardness, moistness, and purity. A person whose block of wax was overly hard or soft and muddy or impure would suffer intellectual deficits. Thomas Aquinas, writing in the thirteenth century CE, believed the comprehension skills of intelligent people to be more nearly complete and universal than those of unintelligent people. According to Aquinas, however, even the most intelligent person could not approach the omniscience of

God. The eighteenth-century philosopher Immanuel Kant believed that there are different kinds of intelligence or perhaps different facets of intelligence, and that people clearly differed in the degree to which they possessed them.

These (and many other) early philosophical explorations of the human intellect foreshadowed the explosion of intelligence research that would occur in the twentieth century. Even though ideas about the nature of intelligence have existed for thousands of years, much of what we know about intelligence has been discovered since the late nineteenth century. We turn now to the implicit metaphors that appear to have guided scholarly exploration into the nature of intelligence, both historically and in modern times (Sternberg, 1990).

Geographic Metaphor

A map of a geographical region provides us with information about the important features of the region, such as major cities, bodies of water, and political borders. Theories of intelligence that embody the geographic metaphor represent an attempt to develop a map for the human mind. Literal conceptions of ''mental maps'' can be traced back to the pioneering work of phrenologist Franz-Joseph Gall (see Boring, 1950), who, working in the late eighteenth century, believed that the pattern of bumps and swells on the skull was directly associated with one's pattern of abilities. Although phrenology itself was not a scientifically valid technique, the practice of mental cartography lingered, giving rise to more modern and, one would hope, more creditable theories of intelligence.

More modern geographic theories of intelligence are devoted to identifying the basic intellectual abilities, called ability *factors*, that supposedly underlie the range of intelligent things people can do. The foundation of this approach was the observation that scores on tests of various mental abilities correlated positively with one another, meaning that someone who performed well on one test was likely to perform well on another test and vice versa. Scholars in the early to mid-1900s concluded that some underlying capability (or set of capabilities) must give rise to this relation between test performances, and developed statistical means for identifying basic ability factors. Identifying factors of intelligence is roughly analogous to identifying the health conditions that give rise to a particular set of correlated symptoms (see figure 1.1). An ability factor is analogous to the health condition, and skills measured by ability tests, such as a vocabulary scale or mathematical word problems, are analogous to symptoms. The main differences between the various geographic theories of intelligence are in the number of ability factors (ranging from one factor to 180!) and in the particular factors identified.

One ability factor or many?

Charles Spearman (1927), a British psychologist working at the turn of the twentieth century, proposed two kinds of factors, general ability (which he called "*g*"), and specific abilities (which he called "*s*," see figure 1.2). Spearman claimed that *g* is a single mental capability measured by all intelligence tests, and that it is some form of generalized *mental energy*. Specific abilities are capabilities uniquely measured by a particular mental test, for example, mathematical computation.

Spearman was interested primarily in what is common among various types of intellectual abilities, rather than in what makes each one unique, much as someone wishing to understand the nature of mammals would study what makes seemingly diverse creatures (e.g., mice, humans, dolphins) similar. He believed that specific abilities do not capture the essence of intelligence and instead proposed that important differences in people's mental test scores are due to just one intellectual capability, mental energy. Spearman was not the first person to believe that the human intellect could be described by a single capability, this view can be traced back at least as far as Aristotle (Detterman, 1982). However, Spearman was the first to explore the topic using rigorous empirical and statistical techniques.

Sir Godfrey Thomson (1939), one of Spearman's rivals, proposed that instead of mental energy, *g* actually consists of many different intellectual capabilities, plus skills and motivation, which operate simultaneously when people take mental tests. As an analogy, the ability to drive a car might appear to be a single skill, but only because multiple skills are all brought to bear on a single larger operation, namely, that of driving the car.

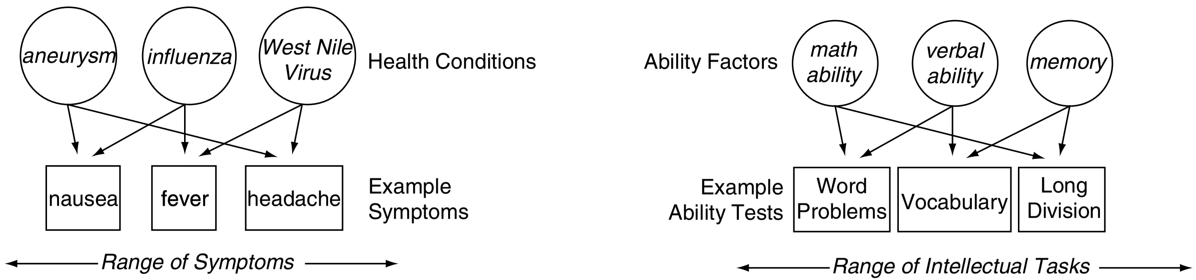

Figure 1.1 *Conceptual Representation of Geographic Theories of Intelligence*

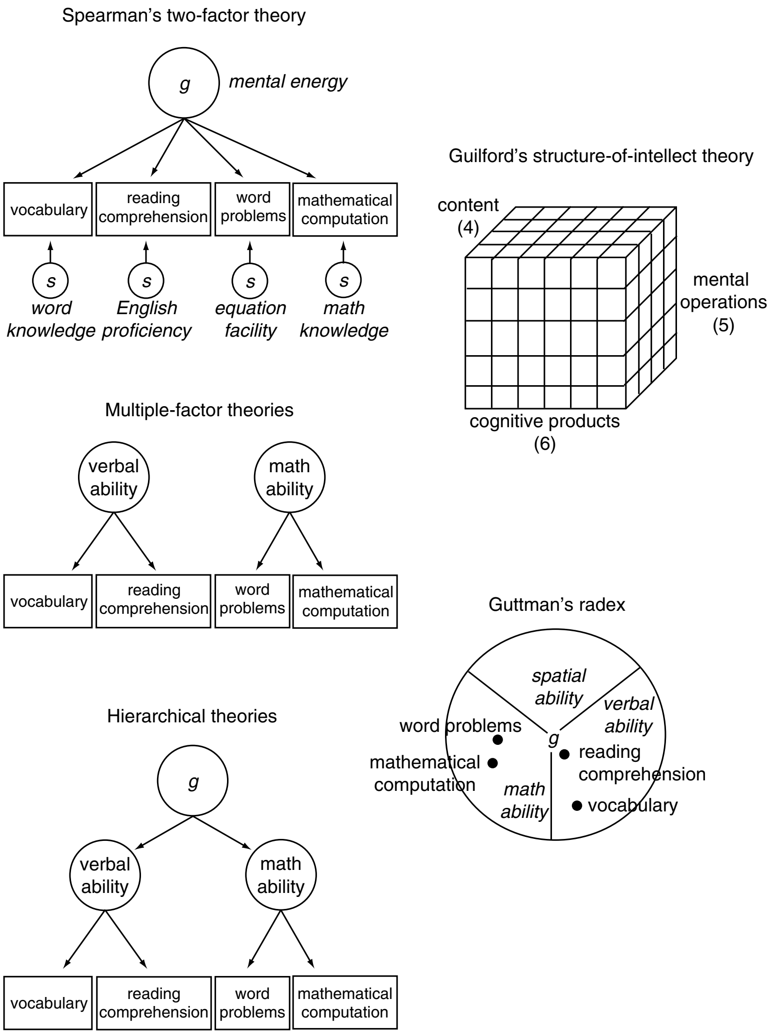

Figure 1.2 *Geographic Theories of Intelligence*

American psychologist Louis L. Thurstone (1938) was perhaps the most influential of the psychologists who disagreed with Spearman. Thurstone contended that intelligence comprises seven distinct but interrelated factors: verbal comprehension, verbal fluency, number (arithmetic computation and problem solving), memory, perceptual speed, inductive reasoning, and spatial visualization. (See figure 1.2 to understand how single-factor theories and multiple-factor theories, such as Thurstone's, differ.) Metaphorically, Spearman proposed one ''health condition'' underlying a wide set of ''symptoms,'' whereas Thurstone believed there are seven health conditions, each with its own set of symptoms. The idea that there exist multiple intellectual capabilities, and that people can have different patterns of strengths and weaknesses in these abilities, dates at least as far back as the sixteenth century (Detterman, 1982). Like Spearman, however, Thurstone was among the first to mathematically explore the geography of the human intellect (see also Blinkhorn, 1995).

Taking a different approach, J. P. Guilford also argued against the idea of general intelligence, or *g*. His structure-of-intellect theory (Guilford, 1956) involved no less than 120 distinct abilities (see figure 1.2). The abilities in Guilford's theory each involved a different content (figural, symbolic, semantic, or behavioral), cognitive product (units, classes, relations, systems, transformations, or implications), and mental operation (cognition, memory, divergent production, convergent production, or evaluation) aspect. For example, one of these abilities was *memory for semantic units*, measured by a test of word recall. Later revisions of Guilford's theory featured 150, and even up to 180 distinct abilities (e.g., Guilford, 1982). There have been many crippling challenges to Guilford's theory, namely the ubiquitous intercorrelation of ability factors. However, Guilford's work did make an important contribution to test construction in that his content, product, and operation dimensions have proven useful for categorizing types of mental tests.

Hierarchical theories of intelligence – a compromise

In hierarchical theories of intelligence, general intelligence is at the top of the hierarchy, and more specific abilities, such as verbal ability or numerical ability, are lower in the hierarchy (see figure 1.2). Intelligence research at the beginning of the twenty-first century primarily bears the thumbprint of two hierarchical theories, those of John L. Horn and Raymond B. Cattell (1966) and of John B. Carroll (1993).

Horn and Cattell's theory features nine abilities at the top of the hierarchy, but the best known of these abilities are crystallized ability and fluid ability. Fluid ability is defined as flexibility of thought and abstract reasoning capability. Crystallized ability is defined as the accumulation of knowledge and skills. Relatively more recent depictions of ability hierarchies featuring fluid and crystallized ability show fluid intelligence at the top, equated with Spearman's *g*, and the other abilities below (e.g., Gustafsson, 1984). Carroll's (1993) hierarchical theory, called the three-stratum theory, is based on an extensive reanalysis of nearly every major data set featuring tests of intellectual ability. At the top of the hierarchy (Stratum III) is general intelligence. The second stratum abilities include fluid ability, learning and memory, and perceptual speed, among others. The first stratum, comprising narrow abilities, includes mathematical reasoning (an aspect of fluid ability) and perceptual closure (an aspect of perceptual speed), among others.

Other depictions related to the hierarchical model include the innovative *radex* model, first put forth by Louis Guttman (1954) and later expanded by Marshalek, Lohman, and Snow (1983). In the radex model, ability tests are arrayed along a circle (see figure 1.2). General intelligence is located at the center of the circle. Tests located closer to *g* measure abilities that are more complex, such as verbal analogical reasoning, and therefore are believed to demand more mental energy. Tests falling closer to the periphery of the circle measure simpler abilities requiring less mental energy, such as short-term memory. Also, tests that are more similar to one another (e.g., vocabulary and reading comprehension) are located closer together in the circle than are tests that are less similar (e.g., reading comprehension and mathematical computation). Phillip L. Ackerman (1988) has extended the radex model to reflect the relative speed requirements of different tests. His depiction of the radex is cylindrical, with tests requiring greater speed in their execution located toward the bottom of the cylinder.

Geographic theories of intelligence have shown us the distinct kinds of abilities that can be measured by mental tests. They also have provided a means for determining how people differ in the degree to which they possess these abilities. However, just as geographic maps do not explain what a river or a mountain range is, geographic theories of intelligence do not explain what an ability factor is. What, for example, is mental energy? Is it the ability to perceive information rapidly? Is it the ability to maintain attention on something in the face of distraction? Or is it something else? Theories based on the computational metaphor have been, in part, an attempt to address this shortcoming, and since the late 1970s theorizing about intelligence has featured various degrees of integration of the geographic and computational perspectives.

Computational Metaphor

Computational theories of intelligence use the computer as a metaphor for explaining what intelligence is. They use terms such as *information processing* to characterize what goes on in the mind when people engage in intellectual activities. One might wonder why it is necessary to explain what intelligence is or how it works. To answer this question, think about an automobile. Just as we know that abilities are required for performing intelligently, we know that engines are required for cars to work. For many of us, this explanation might be all we need; but if we want to go beyond describing our vehicle, for instance to be able to diagnose and fix problems, we would need to know how engines work. Similarly, if we can understand how intelligence works, we can begin to develop ideas for how to diagnose mental disability and improve mental functioning through classroom instruction or cognitive therapy. We will focus our discussion on two types of computational approaches: (1) approaches designed to explain why people differ in their intellectual ability, and (2) approaches designed to understand how intelligence works in all humans.

Origins of the computational approach

Although he is best known for his two-factor theory of intelligence, Spearman (1923) was also one of the first to conceptualize intelligence as a set of cognitive processes. His theory emphasized the importance to intelligent behavior of perceiving stimuli and determining how stimuli are similar and different. The influence of Spearman's work readily can be seen in modern computational theories and was an important beginning for specifying the mental procedures people follow to behave intelligently.

Why do people differ in their intelligence?

Approaches to answering this question have been many and varied, but all have focused on identifying differences in cognitive processes that could explain differences in ability-test scores. In what is called the *cognitive-training* approach (Campione, Brown & Ferrara, 1982), psychologists provide training on a cognitive process they believe to be most important for test performance. If scores improve, they conclude that differences in the efficiency of that cognitive process explain why people have different scores on the test. As an analogy, imagine someone who believes that the most important aspect of baseball pitching is speed. So, he coaches his players to pitch faster balls with the expectation that they will throw more strikes. If they do increase the speed of their pitching but do not throw more strikes, he then concludes that the essence of pitching must not be speed but something else. By exposing the teachability of some cognitive processes, the cognitive-training approach has had some measure of practical relevance. It has not proven viable as a theory-testing approach, however, because it often assumes that all people use the same mental procedures to complete test items, when often they do not.

In the *cognitive-components* approach introduced by Sternberg (1977), intelligence-test problems are broken down into their component parts and the importance of each part to performance on the entire problem is analyzed. For example, if a test problem is the analogy "HORSE is to SADDLE as BIKE is to SEAT," one component involves inferring the relation between HORSE and SADDLE. The components with the strongest and most consistent relation to overall task performance are taken to be the most critical cognitive processes. The cognitive components approach is no longer a dominant approach in modern computational intelligence research, but the influence of this groundbreaking work is evident in current efforts to create test problems that assess particular cognitive processes.

In the *cognitive correlates* approach, introduced by Earl Hunt and his colleagues (Hunt, Frost & Lunneborg, 1973), performance on tasks believed to tap very basic, fundamental cognitive processes (such as retrieving letter names from memory) are correlated with performance on tests of intellectual ability. If the correlation is strong, the basic cognitive process is taken to be critical for test performance. Initial results using this approach were only moderately promising because performance on simple cognitive tasks does not show a strong relation to performance on tests of intellectual ability (Hunt, Frost & Lunneborg, 1973).

The studies of Randall Engle and his colleagues (Engle, Tuholski, Laughlin & Conway, 1999; Hambrick, Kane & Engle, in press) and of Patrick Kyllonen and Raymond Christal (1990) represent more recent applications of the cognitive-correlates approach. This work has explored the relationship between working memory and general intelligence. Working memory is defined as a memory system that has both a storage and a processing component (Baddeley, 1986). It is used when people try simultaneously to hold information in their mind (e.g., a string of three digits) and to execute some kind of cognitive operation on the information (e.g., determining which of the three digits is the smallest). Kyllonen and Christal first demonstrated a strong correlation between working memory and general intelligence. Engle and his colleagues have explored what working memory and general intelligence have in common. They assert that the information processing engaged during working memory tasks involves maintaining attention in the face of distraction, and is an important aspect of all tasks that require working memory or intelligence.

Other investigations of the nature of intelligence also include measures of information processing, such as reacting quickly to a stimulus (Jensen, 1982, in press) and inspecting the similarity/difference of two stimuli (Deary, 1999). In reaction-time tasks, people are asked to respond quickly (e.g., by pressing a button) to the onset of a stimulus (e.g., a light). Jensen found that faster and more consistent responding was associated with higher IQ. In inspection-time tasks, people are given a brief presentation of a pair of stimuli (usually two lines) and must determine if they are the same or different. The amount of time that the stimuli must be shown before a person achieves a certain level of accuracy is called inspection time. Inspection time has shown a notable correlation with IQ and with certain neurological functions (Deary & Caryl, 1997).

How are all people similar in their intelligence?

A subset of computational intelligence research, based in a field of study called cognitive science, has since the 1950s focused on human ability to learn, solve problems, make decisions, and adapt to the environment. For example, one of the computational models developed to explore learning and reasoning processes is based on John Anderson's (1983) ACT* theory of cognition and its more recent extensions (ACT-R, see, for example, Anderson & Schunn, 2000). Anderson has posited that skill acquisition occurs over a series of stages during which people first learn the rules for accomplishing some task, and then create procedures for executing the rules, which eventually become automatic with practice. For example, people learning how to type begin by taking careful note of where they place their fingers. They then learn the patterns of finger movements for creating words and quickly increase the speed with which they execute these patterns. The artificially intelligent computer systems designed by these researchers help us understand how people might learn, apply rules, and use knowledge in order to behave intelligently.

Intelligence research based on the computational metaphor has long held promise for explaining what intelligence is and why people differ in their intellectual abilities. However, human thinking is not computer-like, and the link between the cognitive mechanisms featured in computational theories and actual neurological functions is unclear. Biological approaches to understanding the nature of intelligence provide a means for understanding what exactly happens in the brain during information processing, and how differences in that activity gives rise to differences in intelligent behavior.

Biological Metaphor

Inevitably, when we think about the nature of intelligence, we ponder its origins in the brain. All thought originates in the brain, so eventually we must be able to trace intelligent behavior back to its neurological source. As with computational approaches to understanding intelligence, biological approaches primarily address the questions of (1) why people differ in their intellectual ability and (2) how intelligence works in all humans. Instead of using computational metaphors to answer these questions, the biological approach seeks these answers in the biology of the brain.

For example, to understand why people differ in intellectual ability, the biological approach involves exploring how differences in neurological characteristics, such as brain size or volume, or differences in neurological functioning relate to differences in intelligence-test scores. To understand how intelligence works in all humans, the biological approach involves determining how various intelligent behaviors are represented in the human brain. In short, biological approaches attempt to determine what it is about smart people that makes them "brainy." Research based on the biological metaphor often involves theory and measurement based in the geographic and computational metaphors in order to build a more complete understanding of the nature of intelligence.

Why do people differ in their intelligence?

Numerous techniques for studying the brain and its functioning have been used in the attempt to explain why people differ in their scores on intelligence tests. Dating back to the late 1800s, the measurement of head size (a proxy for brain size) is perhaps the longest-standing and most controversial approach to understanding the cerebral basis of intelligence (e.g., see Gould, 1996). Head size has shown a consistently positive (albeit weak) relationship to scores on various standardized intelligence tests (Vernon, Wickett, Bazana & Stelmack, 2000), indicating that greater head (brain) size is, on average, associated with higher intelligence-test scores. Brain volume has also shown a modest positive correlation with intelligence-test scores (MacLullich, Ferguson, Deary, Seckl, Starr & Wardlaw, 2002; Vernon, Wickett, Bazana & Stelmach, 2000). It is unclear at this time, however, whether brain volume should be considered a cause of greater intelligence or whether factors giving rise to greater intelligence, such as having experienced a larger set of intellectually demanding events, contribute to greater brain volume (e.g., see Garlick, 2002). In any case, the association between brain volume and intelligence appears weak enough to justify searching in other places for the cerebral basis of intelligence.

Technological developments since the late 1800s, such as the *electroencephalogram* (*EEG*), *positron emission tomography* (*PET*), and *functional magnetic resonance imaging* (*fMRI*), have provided a means for exploring the inside of the working brain in a noninvasive way and for studying the neurological functioning associated with doing particular mental tasks. EEGs record electrical currents in the brain, called *electrocortical activity*, which change as a function of what the brain is doing. PET provides an image of how the brain is using blood flow and glucose while engaged in particular activities. Like PET, fMRI also provides information about what regions of the brain are active during mental tasks, though fMRI uses different techniques and has greater imaging capability. Studies using these technological developments suggest that the efficiency of various neurological functions may play an important role in why people perform differently on tests of intelligence (Vernon, 1993).

Electrocortical Activity

Researchers using an electrophysiological approach to understanding intelligence differences examine the correspondence between intelligence-test scores and the speed of a particular type of electrocortical activity, called P300. The P300 is determined by averaging together several EEGs recorded during the performance of a particular kind of task. P300 occurs in tasks that involve detecting, recognizing, and classifying stimuli. Detecting, recognizing, and classifying are information processes used, for example, when a person recognizes a new brand of orange juice at the grocery store (Vernon, Wickett, Bazana & Stelmack, 2000). Quicker onsets of P300 activity following stimulus presentation typically have been associated with higher intelligence test scores (Deary & Caryl, 1997). This relationship suggests that faster neurological functioning is associated, on average, with greater intelligence. The relation between the speed of P300 onset and intelligence has not been consistent, however, and has been shown to depend on the intelligence test chosen. New developments in electrophysiological approaches involve analyzing how changes in electrocortical activity are related to performance on cognitive tasks (Neubauer & Fink, in press). The results so far indicate that greater efficiency of cortical activity is associated with higher IQ.

Cerebral Blood Flow and Glucose Metabolism

The brain's use of blood and glucose is determined using PET. In PET, a scanner detects photons emitted from a radioactive substance that has been injected into research participants immediately before they perform a mental task. The pattern of photons detected by the PET scanner provides information about how the brain uses blood and glucose during intellectual activities. People performing better on reasoning tasks tend to show less blood flow and glucose uptake while engaged in these tasks (Haier, 2003), suggesting that the brains of more intelligent people are more efficient than those of less intelligent people. This finding is inconsistent across studies, however; higher-ability people have demonstrated *greater* rates of glucose uptake than lower-ability people while performing a relatively difficult task.

Activation Levels

Similar to PET, fMRI also indicates levels of activity in the brain. However, fMRI does not use radioactive substances to trace blood flow. Instead, it uses a very powerful magnet, which generates a magnetic field of nearly 10,000 times the strength of the Earth's natural magnetism. The hydrogen atoms in particular parts of the body align differently with this magnetic field, which allows for relatively precise localization of active brain regions. Information is also provided by fMRI that PET cannot supply about the time course and coordination of neurological activation during the performance of intellectually demanding tasks.

Mirroring findings based on PET, fMRI studies have also indicated that greater levels of activation in the brain are associated with both higher and lower levels of performance (Bunge, Ochsner, Desmond, Glover & Gabrieli, 2001). More specifically, greater levels of activation in certain areas of the frontal lobes have been associated with greater ability to resist interference when performing a working memory task, whereas greater levels of activation in other areas have been associated with lesser ability to deal with working memory load (Bunge, Ochsner, Desmond, Glover & Gabrieli, 2001). In another study, increased activation in areas on the left side of the frontal lobes was associated with concept learning, such that concept learners showed this activation, but nonlearners did not (Seger, Poldrack, Prabhakaran, Zhao, Glover & Gabrieli, 2000).

How is intelligence represented in the human brain?

Scientists use either PET or fMRI to investigate the regions of the brain that ''light up'' when people engage in intellectual activity. Findings based on the use of PET and fMRI generally support one another (Newman & Just, in press), namely that neurological activity during intellectually demanding tasks is localized in the frontal lobes of the brain (Duncan et al., 2000; see also Engle, Kane & Tuholski, 1999; Neubauer & Fink, in press). The intellectually demanding tasks studied have included working memory (e.g., Prabhakaran, Narayanan, Zhao & Gabrieli, 2000) and reasoning (e.g., Christoff & Gabrieli, 2000; Prabhakaran, Rypma & Gabrieli, 2001).

More specifically, the front-most portion of the frontal lobes, called the *frontopolar cortex*, has been implicated in reasoning activities that involve generating and evaluating strategies (Christoff & Gabrieli, 2000). The region of the frontal lobes directly behind the frontopolar cortex, called the *dorsolateral cortex*, has been implicated in simpler tasks, such as sorting based on color or shape (Christoff & Gabrieli, 2000). In addition, different sides of the frontal lobes have been implicated in doing working-memory tasks that involve spatial and nonspatial processing (Prabhakaran, Narayanan, Zhao & Gabrieli, 2000). Activation in regions on the right side of the frontal lobes has been associated with the integration of verbal and spatial information in working memory, whereas regions on the left side of the frontal lobes have been associated with nonspatial working memory alone (Prabhakaran, Narayanan, Zhao & Gabrieli, 2000).

Although much work remains before the biological approach can provide definitive results about the cerebral basis of intelligence, the promise of integrating biological with other approaches for understanding intelligence makes continued efforts highly worthwhile. Indeed, much recent theorizing about intelligence (e.g., Duncan, Seitz, Kolodny et al., 2000; Engle, Kane & Tuholski, 1999; Plomin, 2002) reflects a merging of perspectives based in the geographical, computational, and biological metaphors. With such integrated approaches, we may someday be able to describe precisely how the brain changes as people learn and develop intellectually (see, e.g., Garlick, 2002) and what neurological differences characterize people of different intellectual capabilities.

At this point it is worth to noting that the geographic, computational, and, relatively recently, the biological approaches have dominated much psychological exploration of the nature of intelligence. Much of what we know about intelligence is indebted to work done using approaches based on one or some combination of these perspectives. Perhaps because of the predominance of these perspectives, reviews of intelligence research sometimes exclude other, less traditionally psychological perspectives (e.g., Deary, 2001). We believe that the work of psychologists studying other phenomena (e.g., how intelligent behavior develops), as well as philosophers, sociologists and anthropologists, also sheds light on what it is that allows people to behave intelligently and adapt to the world around them.

In particular, the work of these other scholars suggests ways to systematically characterize intellectual behavior as it occurs outside of the testing situation typically studied by traditional intelligence theorists. This work also suggests ways to begin conceptualizing the role of the environment in the development and expression of intelligent behavior. Ultimately, the findings of this work should inform scientific psychological theories of intelligence because it allows for a more complete representation of what it means to be intelligent. It is therefore necessary to present ''alternative'' perspectives on the nature of intelligence and to discuss what research based on these perspectives has to offer our understanding of the nature of intelligence.

Epistemological Metaphor

An epistemology is a formal theory of knowledge—its nature, its limits, and its validity. A theory of intelligence that can be called epistemological therefore has knowledge acquisition as its central focus. This kind of theory details how intelligence develops through the construction of a person's thinking processes and knowledge structures. The foundation of epistemological theories of intelligence rests primarily on the work of one psychologist, Jean Piaget, who sought to understand children's acquisition of logical thinking and scientific knowledge. Some readers of this book may already be familiar with Piaget because his profound thinking about mental development has been enormously influential in both the scientific and popular arenas.

Piaget (1972) theorized that intellectual competence develops in a series of four stages, which begin in infancy and are completed by approximately 16 years of age. In the first stage, the *sensorimotor* stage, which spans from birth to approximately two years of age, infants refine and elaborate on innate reflexes, such as grasping and sucking, and begin to discover through trial and error how their actions lead to outcomes. At the end of this stage, children can understand that objects that are out of sight still exist, and can be found if sought.

The second stage, the *preoperational* stage, spans from approximately two to seven years of age. Language acquisition begins during this stage, although thinking about natural phenomena is not yet well developed. Children in this stage display animistic thinking, assigning the characteristics of people or other animals to inanimate objects (e.g., ''the fire is hungry for wood'').

In the *concrete operations* stage, from the ages of seven through to 11, children can distinguish objects based on their physical characteristics, such as color, size, or shape, and can also order objects, for example, from smallest to largest. The critical cognitive operation acquired during this stage is that of conservation. A child capable of conservation can distinguish between changes in the appearance of a quantity and changes in the quantity itself. For example, such a child knows that she has the same amount of milk whether it is presented in tall, narrow glass or in a short, wide cup.

Children enter the final stage, *formal operations*, around the age of 11 and remain there throughout adulthood. Children and adults capable of formal operational thought exhibit systematic problem-solving skills, including the ability to view a problem from multiple points of view. People in this stage will approach the world in a scientific way, learning by testing their hypotheses about the world and revising their incorrect ideas.

Piaget believed that cognitive development permits children to develop a realistic understanding of the world. In addition to his four stages, he specified two ways that children develop this understanding: *assimilation* and *accommodation* (Piaget, 1972). During assimilation children absorb new information from the environment and fit it into their preexisting knowledge structures. For example, a child would add poodles to his list of dog breeds after seeing one for the first time. To accommodate, children form new knowledge structures to absorb what they have learned. If a child thought that all dogs have long hair, his encounter with a poodle would require him to modify what he believes about dogs.

Neo-Piagetian theorists, including Robbie Case, Kurt Fischer, and Juan Pascual-Leone (Case, 1985, 1999; Fischer, 1980; Mascolo & Fischer, 1998; Pascual-Leone, 1979, 1995), have modified and extended Piaget's original theory. Similar to Piaget's theory, neo-Piagetian theories feature a set of stages or levels of cognitive development, which rely to some degree on physiological maturation. Neo-Piagetian theories also recognize that children play an active role in their own intellectual growth through exploration and inquiry.

Piagetian and neo-Piagetian thinking differ with regard to what develops in each stage and how it is developed. Neo-Piagetian theories often invoke the computational metaphor for explaining how intellectual growth occurs. That is, the development of such information processes as working memory or attention is believed to underlie the acquisition of knowledge and intellectual behavior (e.g., Halford, 1999). Pascual-Leone (1995), for example, believes that a child's progression through the stages of development is a function of the physiological maturation of attentional processes, which allow the child to engage in goal-directed activity and to manipulate greater amounts of knowledge and information at one time. Neo-Piagetians also differ from Piaget in that they embrace the role of environment or culture in shaping the content of people's thought, whereas Piaget did so only minimally (Case, 1999).

Epistemological theories have been critical for turning attention to how intelligent behavior develops, a topic often neglected by theorists guided by the metaphors described previously. However, stage-based theories of intellectual development are problematic because intelligence is fluid in its development and does not exhibit strict, stage-like properties. Sociological accounts of intellectual development may account for the fluid nature of intellectual development, and have arisen, in part, as a response to the limitations of epistemological theories.

Sociological Metaphor

Societal influence on intellectual development is the focus of sociological theories of intelligence. These theories draw attention to the fact that every one of us is a collaborator in the development of people's intelligence. According to these theories, we aid in the intellectual development of others, particularly children, by using language, imagery, and objects to share knowledge and make concepts clearer. We also shape the intellectual behavior of others through our own attitudes about intelligence, intelligence testing, and education.

Like epistemological theories of intelligence, sociological theories of intelligence are founded primarily on the thinking of one psychologist, Lev Vygotsky. Vygotsky (1978) viewed culture as central to intellectual development. He believed that people use what he called *psychological tools* to enhance the thinking of other people. Psychological tools are the language, imagery, thinking styles, and other artifacts in a particular culture used to enhance human mental capability. They work in much the same way that physical tools do to enhance human physical capability.

For example, a more capable cook might aid the thinking of a less capable cook by using language to describe the procedures for making a smooth, flavorful white sauce. The more capable cook would tell her student to be sure to keep the heat under the pan low and to stir the sauce frequently. The more capable cook might also use gestures, demonstrating the sweeping spoon strokes necessary to keep the fluid moving over the heat source. Vygotsky would consider the verbal instruction and the gestures to be psychological tools. Through this instruction, the less capable cook develops his own psychological tools, such as his own set of terminology and procedures for preparing white sauce that he can then pass on to his own students. Language also allows people to regulate their behavior through inner speech, which Vygotsky believed to be critical for learning and intellectual competence.

Vygotsky introduced the concept of the *zone of proximal development* to characterize the situations in which psychological tools are shared and mastered, such as the example of a cook just presented. He defined this zone as the difference between what a person is capable of doing unassisted and what the person can accomplish with help. The greater the difference between what a person can do assisted versus unassisted, the greater the zone of proximal development. *Mediated learning experience*, as defined by Reuven Feuerstein (Feuerstein, 1980), is very similar in spirit to Vygotsky's zone of proximal development. Through mediated learning experience, a more capable person influences the cognitive development of a less capable person by carefully and consciously structuring the learning environment. Feuerstein believed that the instructional effort of the more capable person, or *mediating agent*, was guided by such factors as intention, culture, and emotional investment.

Vygotsky and Feuerstein attempted to identify the processes through which social factors have an effect on cognitive development. More recent work attempts to identify particular societal influences on cognitive development. This work does not typically feature a theory of intelligence, but informs intelligence theory by highlighting the effects that particular socializing agents have on intellectual competence. Such agents include notions of intelligence held in school environments and in family systems.

"School's-eye" views of intelligence

Shirley Brice Heath (Heath, 1983), an ethnographer, studied mismatches between notions of intelligence held in the home and those held in the school environment, and observed the effects of these mismatches on the development of language in children. In three communities, Heath discovered that as home socialization practices diverged from those valued by school environments, performance in school suffered. For example, in one community, verbal interaction typically involved highly fanciful storytelling and clever put-downs. Students from this community experienced difficulty in school, where fanciful stories were perceived as lies, and put-downs were not a valued part of the school's social environment. In another community, parents modeled their verbal exchanges after modes of knowledge transmission in the church, which discouraged dialogue and fantasy. Students from this community excelled in verbatim recall, but experienced great difficulty when novel storytelling was required.

Similarly, Okagaki and Sternberg (1993) found that different ethnic groups in San Jose, California, had rather different conceptions of what it means to be intelligent, which had implications for school performance. For example, Latino parents of schoolchildren tended to emphasize the importance of social-competence skills, whereas Asian parents and Anglo parents tended rather heavily to emphasize the importance of cognitive skills. Teachers, representing the dominant culture, tended to reward those children who were socialized in a view of intelligence that happened to correspond to their own. The rank order of children of various groups according to performance could be perfectly predicted by the extent to which their parents shared the teachers' conception of intelligence.

Family systems

Family systems exert their influence on cognitive development through multiple complex practices, including marital interactions between parents, parenting styles, sibling interactions, and whole-family interactions (see Fiese, 2001). In addition, the way children perceive these practices may also influence cognitive growth. The examination of families has indicated that, in general, parents who are nurturant while maintaining high expectations for intellectual performance tend to have children who exhibit greater levels of intellectual development and school achievement than children whose parents are more permissive (Okagaki, 2001). The positive influence of this parenting style appears to have its effect through increased parent involvement in the child's school activities. The exact mechanisms through which family systems influence cognitive growth are not yet well defined, however, and the effects found are somewhat inconsistent. That is, different parenting styles have different effects depending on the ethnicity of the family, but it is unclear why.

Diverse notions of intelligence generally converge on the fundamental purposes of intelligence—adaptation to the environment and learning from experience. By turning attention to factors outside of the head, sociological views of intellectual development open the door to defining what the environment is for particular people or groups of people, and how environments shape intellectual growth. These views do not, however, shed light on how different environments shape what it means to be intelligent. For insight into this issue, we turn to anthropological approaches for exploring intelligence.

Anthropological Metaphor

Anthropological conceptualizations of intelligence see culture as central to defining what it means to be intelligent. The view that culture is an important influence on the nature of intelligence runs counter to what many believe—that someone who is smart and successful in one culture is largely guaranteed to be smart and successful in another. The concern of anthropologists and many psychologists studying intelligence is that assessments of intelligence can be culturally biased if not designed carefully (Greenfield, 1997). This would result in people being ''smart'' when they take tests designed by people from their own culture, and ''dumb'' when they take tests designed by people from other cultures. As shown in Heath's (1983) and Okagaki and Sternberg's (1993) studies above, people in different cultures may develop somewhat different intellectual abilities, depending on what types of intellectual competence are valued by their particular culture.

And, indeed, substantial differences have been demonstrated in conceptualizations of what it means to be intelligent in cultures around the world. Gill and Keats (1980), for example, noted that Australian university students value academic skills and the ability to adapt to new events as critical to behaving intelligently, whereas Malay students value practical skills, as well as speed and creativity. Reviewing Chinese philosophical conceptions of intelligence, Yang and Sternberg (1997) found that the Confucian perspective on intelligence, consistent with the Western perspective, views the intelligent person as spending a great deal of effort in learning, enjoying learning, and enthusiastically persisting in life-long learning. The Taoist tradition, in contrast, emphasizes the importance of humility, freedom from conventional standards of judgment, and full knowledge of oneself as well as of external conditions. Das (1994), also reviewing Eastern notions of intelligence, has suggested that in Buddhist and Hindu philosophies, intelligence involves waking up, noticing, recognizing, understanding, and comprehending, but also includes such things as determination, mental effort, and even feelings and opinions in addition to more cognitive elements.

Studies in Africa provide yet another window on the substantial differences. Ruzgis and Grigorenko (1994) have argued that, in Africa, conceptions of intelligence revolve largely around skills that help to facilitate and maintain harmonious and stable inter-group relations; intra-group relations are probably equally important and at times more important. For example, Serpell (1974, 1982, 1993) found that Chewa adults in Zambia emphasize social responsibilities, cooperativeness, and obedience as important to intelligence; intelligent children are expected to be respectful of adults. Notions of intelligence in many Asian cultures also emphasize the social aspect of intelligence more than does the conventional Western or IQ-based notion (Azuma & Kashiwagi, 1987; Lutz, 1985; Poole, 1985; White, 1985).

It should be noted that neither African nor Asian conceptions of intelligence emphasize exclusively social notions. For example, in a study of Kenyan conceptions of intelligence (Grigorenko, Geissler, Prince, et al., 2001), it was found that there are four distinct terms constituting conceptions of intelligence among rural Kenyans—*rieko* (knowledge and skills), *luoro* (respect), *winjo* (comprehension of how to handle real-life problems), *paro* (initiative)—with only the first directly referring to knowledge-based skills (including but not limited to the academic).

The examination of cultural differences in how intelligence is defined opens the door not just to creating culturally fair intelligence assessments but also to discovering more universal (as opposed to Western) truths regarding the nature and expression of intelligence.

Anthropological approaches to understanding intelligence arose in contrast to conceptions of culture and mind prevalent in the late nineteenth century. During this period in history, the belief was that cultures, just as the species of all living things, evolved, and that the minds of the members of cultures evolved along with them. The implication of this belief was that more primitive cultures (which were seen as less evolved) were believed to have members with less evolved intellects. Not surprisingly, nineteenth-century Europe was believed to be the pinnacle of cultural and mental evolution, as evidenced by its scientific, technological, and artistic products. The early twentieth-century anthropologist Franz Boas (1911) first challenged the idea of cultural evolution, arguing that the cultural products in different cultures are too different to be comparable.

Revised conceptions of mental evolution followed. These new ideas maintained a strong link between culture and intelligence, emphasizing the importance of the intellect in aiding people to adapt to cultural and ecological demands. The key assertion, however, was that intellectual sophistication must be understood within the context of particular cultural achievements. One important contributor to these ideas was John Berry (1974), who called himself a radical cultural relativist because he believed that cognitive abilities are culture specific and that cross-cultural comparisons of intelligence cannot meaningfully be made.

Berry emphasized the adaptive role of intelligence—that it responds to ecological demands through the development of mental skills that permit successful task performance. For example, he hypothesized that people in a hunting-based culture would have well-developed visual discrimination and spatial skills because the ecological demands of hunting required these skills for successful performance. He ranked several cultural groups according to the importance of hunting to their survival and compared these rankings with test scores for perceptual discrimination and other related skills. He found, as predicted, that people in cultures ranked as having greater dependency on hunting also had higher scores on the psychological tests.

More recently, Berry (2004) has recast his theorizing in less extreme terms. He now acknowledges the existence of universal cognitive processes (e.g., memory, deduction, etc.), but still assigns a critical role to ecology in shaping how intelligence develops in the people of a particular culture. He also maintains what he calls a ''value-neutral'' conceptualization of cross-cultural differences, meaning that no one culture is seen as more advanced than another.

Adopting a position similar to Berry were Michael Cole and his colleagues at the Laboratory of Comparative Human Cognition (1982). Cole and his colleagues asserted that comparisons of cognitive competence across cultures could be meaningfully made, provided that special care was taken to ensure that tasks used to assess cognitive competence are actually comparable across cultures. For tasks to be comparable across cultures, they must measure the same cognitive capabilities despite surface differences in content. As a very simplistic example, a science test written in English would test science for English speakers, but would largely test guessing ability for non-English speakers. To make the test comparable across the two cultures, a translation, at the very least, would be necessary.

Ype Poortinga and Fons van de Vijver (2004) warn against making assumptions about the nature of cross-cultural differences on tests of intellectual ability. They have demonstrated that carefully designed tests of basic psychological processes, such as memory or reaction time, reveal very little difference in the intellectual capability of people in different cultures. Together with colleague Mustafa F. A. Shebani they found, for example, that memory spans for words in Libyan and Dutch school children were quite different. These differences occurred because Arabic words take longer to pronounce, causing the Libyan children they studied to have slower reading speed. Words that take a longer time to read are more difficult to hold in memory. Memory differences between children in these two cultures were substantially reduced when differences in reading speed were controlled for. Poortinga and van de Vijver recognize that culture often plays a role in test performance, but argue that it is not a foregone conclusion that intellectual competence is different in different cultures.

Anthropological approaches to understanding intelligence raise important questions about ethnocentric influences on experimental and assessment designs. Scientists can unknowingly allow their values to intrude not only into their interpretation of test scores but also into the way they design tests. However, the natural appeal of the anthropological approach can sometimes overshadow the fact that theories of intelligence based on the anthropological metaphor alone are incomplete. They are not intended to address key topics of interest to intelligence theorists, such as why people in the same culture differ in their intellectual capability or how environmental factors influence neurological development.

Systems Metaphor

A system has multiple interdependent parts and its successful overall function is a result of the harmonious interaction of these parts. Computers, national governments, even living things, are all examples of systems. Systems theories of intelligence involve viewing intelligence as a set of multiple interdependent parts, or even multiple intelligences. The successful accomplishment of task objectives or life goals is seen as the result of a complex interaction of these parts. Systems theories of intelligence differ on what these parts are and the nature of their interaction, but all converge on the fact that no single metaphor can adequately describe intelligence. In addition, a key characteristic that distinguishes systems theories of intelligence from other theories that integrate multiple perspectives is that systems theories attempt to address a wider range of intelligent behavior and explicitly posit a role for cultural and other environmental influences on what it means to be intelligent.

Gardner's theory of multiple intelligences

Howard Gardner's (1983, 1999a) theory of multiple intelligences integrates methodological approaches and findings from the geographic metaphor, the biological metaphor, and the anthropological metaphor. Similar to the initial theorizing of geographic intelligence theorists Thurstone and Guilford, Gardner's view of intelligence does not recognize intelligence as a single entity, but rather as a system of independent intelligences. He has proposed eight or possibly more intelligences, which interact to create successful performance, such as in choreographing a Broadway musical or making psychiatric diagnoses. Gardner's intelligences include linguistic intelligence, logical–mathematical intelligence, spatial intelligence, musical/rhythmic intelligence, bodily–kinesthetic intelligence, interpersonal intelligence, intra-personal intelligence, naturalist intelligence, and possibly existential intelligence. Gardner specifies eight prerequisites for the existence of an intelligence, which include biological distinctiveness, unique developmental patterns, and evolutionary plausibility and purpose, among others.

As an example of one intelligence, Gardner defines linguistic intelligence as one's facility with linguistic activity, including reading, writing, listening, and speaking. Professionals, such as journalists, speechwriters, or translators, whose work requires extensive language use, are expected to have a great deal of this intelligence. Gardner uses language disorders produced only by damage to very specific parts of the brain as evidence for the independence of linguistic intelligence from other intelligences. In addition, the evolutionary advantage associated with developing language facility is clear.

Sternberg's triarchic theory of successful intelligence

Robert J. Sternberg's (1988, 1997, 1999) triarchic theory of successful intelligence is an integration of the geographic, computational, and anthropological metaphors. Sternberg defines successful intelligence as the balancing of analytical, creative, and practical abilities to achieve success within a particular sociocultural context. Analytical abilities are used whenever a person analyzes, evaluates, compares, or contrasts pieces of information. Creative abilities are involved in the creation, invention, or discovery of objects or ideas. Practical abilities permit people to practice, apply, or use what has been learned in either formal or informal settings.

Success in life is determined by people's ability to capitalize on their strengths in analytical, creative, and practical abilities and to correct or compensate for their weaknesses. Consider, for instance, a person who has well-developed analytical and practical abilities, but less well-developed creative abilities. In order for this person to be optimally successful, he or she may choose an environment in which analytical and practical abilities are most important for success—perhaps a work team that conducts technical evaluations for outside clients.

The triarchic theory of successful intelligence has three subtheories, which characterize (1) the mental mechanisms that underlie successful intelligence, (2) the way in which people use these mechanisms to attain an intelligent fit to the environment, and (3) the role of experience in mobilizing cognitive mechanisms to meet environmental demands. Using our example from the preceding paragraph, let us suppose the person conducts a technical evaluation and must decide how to compile and present potentially dissatisfying results to a client. The triarchic theory characterizes the problem-solving process that would be passed through as knowledge gained from previous experience is utilized, strategies created for arriving at a successful solution, the problem solution reached, and new knowledge acquired from the experience.

Sternberg's theory specifies not only the kinds of broad abilities (analytical, creative, and practical) that play a role in achieving success, but also the cognitive processes required to apply these abilities and the problem-solving strategies through which success may be achieved. The theory also recognizes a dynamic aspect of successful performance—that success requires not simply applying acquired knowledge, but also coping with novelty and transforming novel experiences into automatic information processing. It states that successful people find a way to capitalize on their strengths and to correct or compensate for their weaknesses.

Ceci's bioecological model of intelligence

Stephen J. Ceci's (1996) bioecological model involves all of the metaphors of intelligence. Ceci rejected the notion of a single intellectual capability, such as general intelligence, and instead posited multiple *cognitive potentials*, which are biological predispositions that enable particular types of critical thinking and knowledge acquisition. For example, a verbal cognitive potential promotes the acquisition and use of vocabulary and verbal skills. Cognitive potentials, knowledge, and environmental context interact to determine individual differences in the development and performance of intellectual behavior. That is, Ceci claimed that biological endowment is not sufficient for intellectual development, but that such development also requires a supportive environment and motivation to grow.

The knowledge base that people have acquired must also be compatible with the demands of the environmental context. For instance, people may acquire knowledge about how to perform mathematical computations in either educational or informal (e.g., marketplace) settings. People having learned mathematical computation in informal settings have been shown to be facile with math when the calculations involve quantities of familiar objects (e.g., coconuts or other produce) but fail to execute the same calculations when the quantities are presented in an unfamiliar testing situation (Ceci & Roazzi, 1994).

We believe that systems theories represent the future of intelligence research, a future that we hope moves the scientific investigation of intelligence toward a more nearly complete account of intelligent behavior. Rather than each of the other metaphors representing a blind man who only has access to one part of the elephant, the systems metaphor holds promise for revealing the nature of intelligence as a complex whole. However, just as there are countless ways mathematically to arrive at the number 100 (e.g., $98 + 2$; 20×5), so are there many ways to combine metaphors to understand intelligence. This multiplicity can result in the creation of potentially countless theories, none of which allows us to understand intelligence any better than the others.

Conclusion

In this chapter, we have presented seven metaphors of mind that scientists studying intelligence hold—geographical, computational, biological, epistemological, sociological, anthropological, and systems. We have discussed the major theories derived from each metaphor in order to show how each metaphor has been used to explore the nature of intelligence. Most importantly, we have attempted to demonstrate that a single-metaphor approach to understanding intelligence is limited. Only a combination of multiple metaphors will allow us fully to understand the complex phenomenon that intelligence is and move intelligence research into the future.

The seven metaphors we have described embody the values and interests that intelligence researchers bring to their investigations. Often unknowingly, scientists allow these metaphors to guide the questions they ask about the nature of intelligence and the methods they use to answer these questions. As we discuss in the next chapter, the metaphor one uses for understanding the nature of intelligence has implications for how intelligence is measured.