Figure 6.1 on p. 273)—diagrams that depict how information flows through the cognitive system. Such flow diagrams can be used, at least in principle, to develop computer simulations of thought. (We look more carefully at such simulations later.)

> History of the Theory

Once developmentalists entered the domain of experimental psychology en masse in the early 1960s, they felt reverberations from every significant event in adult experimental psychology. Information processing was the first major theory of adult cognition to arise since developmental psychology had become an experimental science. This minirevolution within adult experimental psychology gradually changed the prevailing view of thinking in children. The attraction of information-processing theory for developmentalists can be understood only by tracing the chain of events within adult experimental psychology that led from neobehaviorist learning approaches to the information-processing approach.

Two general developments in the 1940s and 1950s eventually transformed adult experimental psychology. First, as described in Chapter 5, a crisis of confidence occurred within learning theory, which led psychologists to seek a more satisfactory approach. For example, typical research on learning an arbitrary association between nonsense syllables, for example "GAV-HIG," seemed to be of limited use for our understanding of human thinking. Also, a young linguist named Noam Chomsky had attacked the learning account of language acquisition. He argued that learning theory's account of language is wrong because it focuses on language output and reinforcement of this output. Chomsky proposed that the essence of language is a set of underlying abstract rules that generate sentences. Thus, the important part of language is unobservable and must be inferred from the relations between language input and output.

The second influential development was the exposure of psychologists to conceptions of information implicit in much of society's new technology. These advances changed the thinking of psychologists forever; theories reflect their times. World War II and the Korean War drew psychologists out of the laboratory because they were needed to improve the human operation of wartime equipment and weapons. Psychologists began to think of humans as information transmitters and decision makers when they examined how military personnel divided their attention between a plane's controls and instructions from a radio, detected blips on a radar screen, and interpreted a plane's instrument readings. A human and a machine (plane or weapon) operate together as a unit. It is

desirable that this unit operate efficiently to avoid unfortunate errors, such as plunging into the ocean.

Another technological influence came from communication engineering and information theory. Engineers working on communication systems, such as the telephone, telegraph, radio, television, and early computers, developed the notion of "communication channels," which came to serve as a metaphor for human thought. Psychologists began to speak of "limited-capacity channels," "serial" (successive) and "parallel" (simultaneous) processing, "coding information" into large units, and "uncertainty" (ambiguous information). Thus, psychologists were not only willing to talk about the mind (as opposed to the behaviorists) but also had a language for doing so. Later, computer scientists' work on more sophisticated computers, robots, and other symbol-manipulating systems suggested to psychologists that people might also be considered symbol-manipulating systems. Newell and Simon (1961), in particular, argued convincingly that the logical capabilities of people could be simulated by appropriate computer programs. The cognitive revolution had begun!

In contrast to information-processing psychologists, who try to model human thinking, the field of *artificial intelligence* tries to develop maximally efficient and intelligent systems. The latter produces robots, computer programs, or other devices that can play chess or other games, translate texts, serve drinks, perform mathematical calculations, and keep track of a store's inventory. These devices often surpass average mental skills, as anyone who has been humiliated by a computer in a chess game can attest. For example, even an early computer chess whiz, "Deep Thought," beat nearly all of its human opponents (Lindsay, 1991), and "Deep Blue" even beat chess expert Garry Kasparov. Both information-processing and artificial-intelligence approaches are part of the contemporary field of *cognitive science*—an amalgamation of cognitive psychology, computer science, philosophy, neuroscience, and linguistics.

Regarding developmental psychology, by the late 1960s researchers were beginning to recognize the potential of information processing for studying children's thinking. Many developmentalists had doubts that Piagetian stage theory had a viable account of cognitive change and thought that information processing might fill this gap. The information-processing approach also was appealing because it permitted controlled experimental studies, as had learning theory, but it also supplied a fruitful new methodology, language, and metaphor for studying the development of thought. In addition, there already was interest in some of the topics studied by information-processing psychologists, particularly

memory, attention, and language. There was a sense of excitement about the future of developmental psychology.

As a result of all of these factors, information processing became a major force in the field of developmental psychology. Numerous studies have examined children's memory, attention, representation, learning, and problem solving over the last 40 years. Recently, connectionist/neural network models, discussed later in the chapter, have caused another surge of interest in information processing.

Most of the early information-processing studies were simply direct translations of the adult research, using children as subjects. For example, researchers gave children simpler versions of the memory and attention tasks they gave to adults. Eventually, as happened in learning theory earlier, developmental research began to go beyond these simple translations and to look at specifically developmental issues.

> General Orientation to the Theory

How do we recognize an "information-processing cognitive developmental psychologist" when we see one? This species has distinctive markings that help "psychologist watchers" identify it. The following field guide describes several characteristics: viewing humans as information-processing systems, conceptualizing development as self-modification, conducting task analyses, and using information-processing methodology. All of these address two main characteristics of human thought: "[O]ur thinking is limited in both speed of processing and the amount we can attend to at any one time, and our thinking is flexible, to get around these limitations and to adapt cognitively to both internal changes such as changed plans and external changes such as a new task" (Siegler & Alibali, 2005, p. 68).

Humans as Information-Processing Systems

We find striking correspondences in how people and computers manipulate input according to certain rules and store the results of these operations. We can compare perceiving with "input," thinking with a "computer program," storage capacity with the number of "K," mental operations with "subroutines," forgetting with hitting the "delete" key, recall with "search," strategies with "tools," and a decision with "output." The structure of the cognitive system sometimes is called *cognitive architecture*. An information-processing psychologist asks, "How are humans programmed to make sense out of the complex world around them?" and "What would an