CHAPTER 1

Thinking and Reasoning: A Reader's Guide

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"*Cogito, ergo sum*," the French philosopher René Descartes famously declared, "I think, therefore I am." Every normal human adult shares a sense that the ability to think, to reason, is a part of their fundamental identity. A person may be struck blind or deaf, yet we still recognize his or her core cognitive capacities as intact. Even loss of language, the gift often claimed as the *sine qua non* of *homo sapiens*, does not take away a person's essential humanness. Unlike language ability, which is essentially unique to our species, the rudimentary ability to think and reason is apparent in nonhuman primates (see Call & Tomasello, Chap. 25); and yet it is thinking, not language, that lies closest to the core of our individual identity. A person who loses language but can still make intelligent decisions, as demonstrated by actions, is viewed as mentally intact. In contrast, the kinds of brain damage that rob an individual of the capacity to think and reason are considered the harshest blows that can be struck against a sense of personhood. *Cogito, ergo sum*.

What Is Thinking?

We can start to answer this question by looking at the various ways the word "thinking" is used in everyday language. "I think that water is necessary for life" and "George thinks the Pope is a communist" both express *beliefs* (of varying degrees of apparent plausibility), that is, explicit claims of what someone takes to be a truth about the world. "Anne is sure to think of a solution" carries us into the realm of problem solving, the mental construction of an action plan to achieve a goal. The complaint "Why didn't you think before you went ahead with your half-baked scheme?" emphasizes that thinking can be a kind of *foresight*, a way of "seeing" the possible future.[1] "What do you think about it?" calls for a *judgment*, an assessment of the desirability of an option. Then there's "Albert is lost in thought," where thinking becomes some sort of mental meadow through which a person might meander on a rainy afternoon, oblivious to the world outside.

Rips and Conrad (1989) elicited judgments from college students about how various mentalistic terms relate to one another. Using statistical techniques, the investigators were able to summarize these relationships in two diagrams, shown in Figure 1.1. Figure 1.1(A) is a hierarchy of *kinds*, or categories. Roughly, people believe planning is a kind of deciding, which is a kind of reasoning, which is a kind of conceptualizing, which is a kind of thinking. People also believe that thinking is *part of* conceptualizing, which is part of remembering, which is part of reasoning, and so on [Figure 1.1(B)]. The kinds ordering and the parts ordering are similar; most strikingly, "thinking" is the most general term in both orderings – the grand superordinate of mental activities, which permeates all the others.

It is not easy to make the move from the free flow of everyday speech to scientific definitions of mental terms, but let us nonetheless offer a preliminary definition of thinking to suggest what this book is about: *Thinking is the systematic transformation of mental representations of knowledge to characterize actual or possible states of the world, often in service of goals*. Obviously, our definition introduces a plethora of terms with meanings that beg to be unpacked, but at which we can only hint. A *mental representation* of knowledge is an internal description that can be manipulated to form other descriptions. To count as thinking, the manipulations must be *systematic* transformations governed by certain constraints. Whether a logical deduction or a creative leap, what we mean by thinking is more than unconstrained associations (with the caveat that thinking may indeed be disordered; see Bachman & Cannon, Chap. 21). The internal representations created by thinking describe states of some external world (a world that may include the thinker as an object of self-reflection) – that world might be our everyday one, or perhaps some imaginary construction obeying the "laws" of magical realism. Often (not always – the daydreamer, and indeed the night dreamer, are also thinkers), thinking is directed toward achieving some desired state of affairs, some goal that motivates the thinker to perform mental work.

Our definition thus includes quite a few stipulations, but notice also what is left out. We do not claim that thinking necessarily requires a human (higher-order primates, and perhaps some other species on this or other planets, have a claim to be considered thinkers) (see Call & Tomasello, Chap. 25) or even a sentient being. (The field of artificial intelligence may have been a disappointment in its first half-century, but we are reluctant to define it away as an oxymoron.) Nonetheless, our focus in this book is on thinking by hominids with electrochemically powered brains. Thinking often seems to be a conscious activity of which the thinker is aware (*cogito, ergo sum*); however, consciousness is a thorny philosophical puzzle, and some mental activities seem pretty much like thinking, except for being implicit rather than explicit (see Litman & Reber, Chap. 18). Finally, we do not claim that thinking is inherently rational, optimal, desirable, or even smart. A thorough history of human thinking will include quite a few chapters on stupidity.

The study of thinking includes several interrelated subfields that reflect slightly different perspectives on thinking. *Reasoning*, which has a long tradition that springs from philosophy and logic, places emphasis on the process of drawing inferences (*conclusions*) from some initial information (*premises*). In standard logic, an inference is *deductive* if the truth of the premises guarantees the truth of the conclusion by virtue of the argument form. If the truth of the premises renders the truth of the conclusion more credible but does not bestow certainty, the inference is called *inductive*.[2] *Judgment and decision making* involve assessment of the value of an option or the probability that it will yield a certain payoff (judgment) coupled with choice among alternatives (decision making). *Problem solving* involves the construction of a course of action that can achieve a goal.

Although these distinct perspectives on thinking are useful in organizing the field

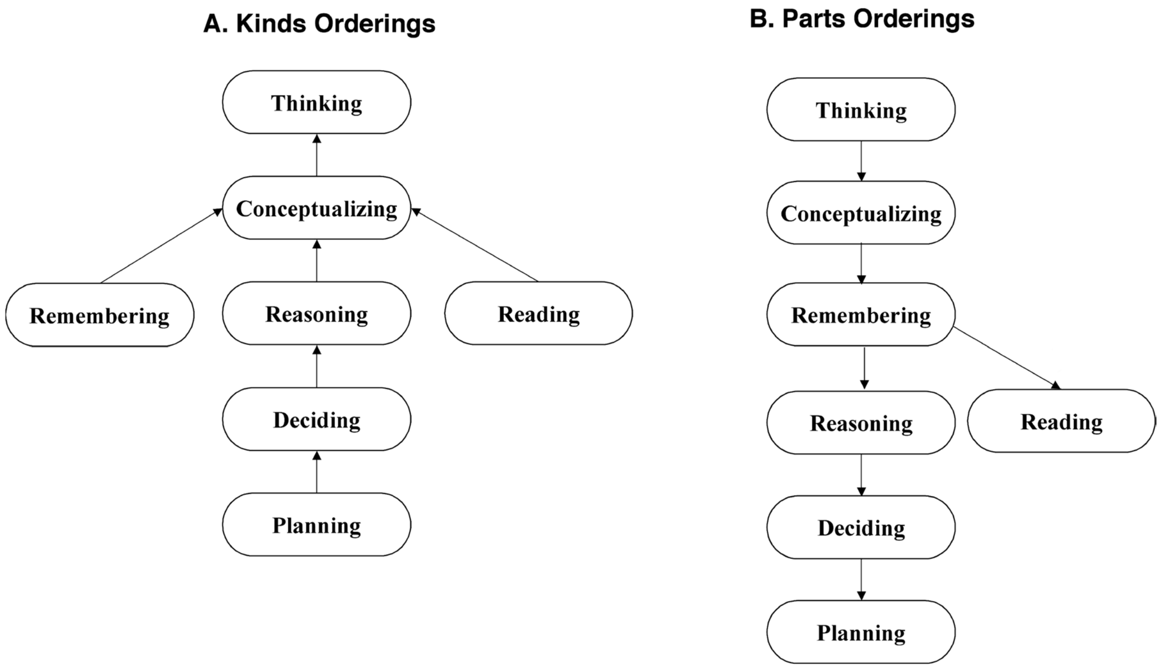

Figure 1.1. People's conceptions of the relationships among terms for mental activities. A, Ordering of "kinds." B, Ordering of "parts." (Adapted from Rips & Conrad, 1989, with permission.)

(and this volume), these aspects of thinking overlap in every conceivable way. To solve a problem, one is likely to reason about the consequences of possible actions and make decisions to select among alternative actions. A logic problem, as the name implies, is a problem to be solved (with the goal of deriving or evaluating a possible conclusion). Making a decision is often a problem that requires reasoning. These subdivisions of the field, like our preliminary definition of thinking, should be treated as guideposts, not destinations.

A Capsule History

Thinking and reasoning, long the academic province of philosophy, have over the past century emerged as core topics of empirical investigation and theoretical analysis in the modern fields known as cognitive psychology, cognitive science, and cognitive neuroscience. Before psychology was founded, the eighteenth-century philosophers Immanuel Kant (in Germany) and David Hume (in Scotland) laid the foundations for all subsequent work on the origins of causal knowledge, perhaps the most central problem in the study of thinking (see Buehner & Cheng, Chap. 7). If we were to choose one phrase to set the stage for modern views of thinking, it would be an observation of the British philosopher Thomas Hobbes, who, in 1651, in his treatise *Leviathan*, proposed, "Reasoning is but reckoning." "Reckoning" is an odd term today, but in the seventeenth century it meant *computation*, as in arithmetic calculations.[3]

It was not until the twentieth century that the psychology of thinking became a scientific endeavor. The first half of the century gave rise to many important pioneers who in very different ways laid the foundations for the emergence of the modern field of thinking and reasoning. Foremost were the Gestalt psychologists of Germany, who provided deep insights into the nature of problem solving (see Novick & Bassok, Chap. 14).

Most notable of the Gestaltists were Karl Duncker and Max Wertheimer, students of human problem solving, and Wolfgang Köhler, a keen observer of problem solving by great apes (see Call & Tomasello, Chap. 25).

The pioneers of the early twentieth century also include Sigmund Freud, whose complex and ever-controversial legacy includes the notions that forms of thought can be unconscious (see Litman & Reber, Chap. 18) and that "cold" cognition is tangled up with "hot" emotion (see Molden & Higgins, Chap. 13). As the founder of clinical psychology, Freud's legacy also includes the ongoing integration of research on normal thinking with studies of thought disorders, such as schizophrenia (see Bachman & Cannon, Chap. 21).

Other early pioneers in the early and mid-twentieth century contributed to various fields of study that are now embraced within thinking and reasoning. Cognitive development continues to be influenced by the early theories developed by the Swiss psychologist Jean Piaget (see Halford, Chap. 22) and the Russian psychologist Lev Vygotsky (see Greenfield, Chap. 27). In the United States, Charles Spearman was a leader in the systematic study of individual differences in intelligence (see Sternberg, Chap. 31). In the middle of the century, the Russian neurologist Alexander Luria made immense contributions to our understanding of how thinking depends on specific areas of the brain, anticipating the modern field of cognitive neuroscience (see Goel, Chap. 20). Around the same time, in the United States, Herbert Simon argued that the traditional rational model of economic theory should be replaced with a framework that accounted for a variety of human resource constraints such as bounded attention and memory capacity and limited time (see LeBoeuf & Shafir, Chap. 11, and Morrison, Chap. 19). This was one of the contributions that in 1978 earned Simon the Nobel Prize in Economics.

In 1943, the British psychologist Kenneth Craik sketched the fundamental notion that a mental representation provides a kind of model of the world that can be "run" to make predictions (much like an engineer might use a physical scale model of a bridge to anticipate the effects of stress on the actual bridge intended to span a river).[4] In the 1960s and 1970s, modern work on the psychology of reasoning began in Britain with the contributions of Peter Wason and his collaborator Philip Johnson-Laird (see Evans, Chap. 8).

The modern conception of thinking as computation became prominent in the 1970s. In their classic treatment of human problem solving, Allen Newell and Herbert Simon (1972) showed that the computational analysis of thinking (anticipated by Alan Turing, the father of computer science) could yield important empirical and theoretical results. Like a program running on a digital computer, a person thinking through a problem can be viewed as taking an input that represents initial conditions and a goal, and applying a sequence of operations to reduce the difference between the initial conditions and the goal. The work of Newell and Simon established computer simulation as a standard method for analyzing human thinking. Their work also highlighted the potential of production systems (see Novick & Bassok, Chap. 14), which were subsequently developed extensively as cognitive models by John Anderson and his colleagues (see Lovett & Anderson, Chap. 17).

The 1970s saw a wide range of major developments that continue to shape the field. Eleanor Rosch, building on earlier work by Jerome Bruner (Bruner, Goodnow, & Austin, 1956), addressed the fundamental question of why people have the categories they do, and not other logically possible groupings of objects (see Medin & Rips, Chap. 3). Rosch argued that natural categories often have fuzzy boundaries (a whale is an odd mammal) but nonetheless have clear central tendencies or prototypes (people by and large agree that a bear makes a fine mammal). The psychology of human judgment was reshaped by the insights of Amos Tversky and Daniel Kahneman, who identified simple cognitive strategies, or heuristics, that people use to make judgments of frequency and probability. Often quick and accurate, these strategies can in some circumstances lead to nonnormative judgments. After Tversky's death in 1996, this line of work was continued by Kahneman, who was awarded the Nobel Prize in Economics in 2002. The current view of judgment, which has emerged from 30 years of research, is summarized by Kahneman and Frederick (Chap. 12; also see LeBoeuf & Shafir, Chap. 11). (Goldstone and Son, Chap. 2, review Tversky's influential theory of similarity judgments.)

In 1982, a young vision scientist, David Marr, published a book called *Vision*. Largely a technical treatment of visual perception, the book includes an opening chapter that lays out a larger vision – a vision of how the science of mind should proceed. Marr distinguished three levels of analysis, which he termed the level of *computation*, the level of *representation and algorithm*, and the level of *implementation*. Each level, according to Marr, addresses different questions, which he illustrated with the example of a physical device, the cash register. At Marr's most abstract level, computation (not to be confused with computation of an algorithm on a computer), the basic questions are "What is the goal that the cognitive process is meant to accomplish?" and "What is the logic of the mapping from the input to the output that distinguishes this mapping from other input–output mappings?" A cash register, viewed at this level, is used to achieve the goal of calculating how much is owed for a purchase. This task maps precisely onto the axioms of addition (e.g., the amount owed should not vary with the order in which items are presented to the sales clerk, a constraint that precisely matches the commutativity property of addition). It follows that, without knowing anything else about the workings of a particular cash register, we can be sure (if it is working properly) that it will be performing addition (not division).

The level of representation and algorithm, as the name implies, deals with the questions, "What is the representation of the input and output?" and "What is the algorithm for transforming the former into the latter?" Within a cash register, addition might be performed using numbers in either decimal or binary code, starting with either the leftmost or rightmost digit. Finally, the level of implementation addresses the question, "How are the representation and algorithm realized physically?" The cash register could be implemented as an electronic calculator, a mechanical adding machine, or even a mental abacus in the mind of the clerk.

In his book, Marr stressed the importance of the computational level of analysis, arguing that it could be seriously misleading to focus prematurely on the more concrete levels of analysis for a cognitive task without understanding the goal or nature of the mental computation.[5] Sadly, Marr died of leukemia before *Vision* was published, and so we do not know how his thinking about levels of analysis might have evolved. In very different ways, Marr's conception of a computational level of analysis is reflected in several chapters in this book (see especially Doumas & Hummel, Chap. 4; Buehner & Cheng, Chap. 7; Lovett & Anderson, Chap. 17).

In the most recent quarter-century, many other springs of research have fed into the river of thinking and reasoning, including the field of analogy (see Holyoak, Chap. 6), neural network models (see Doumas & Hummel, Chap. 4; Halford, Chap. 22), and cognitive neuroscience (see Goel, Chap. 20). The chapters of this handbook collectively paint a picture of the state of the field at the dawn of the new millennium.

Overview of the Handbook

This volume brings together the contributions of many of the leading researchers in thinking and reasoning to create the most comprehensive overview of research on thinking and reasoning that has ever been available. Each chapter includes a bit of historical perspective on the topic and ends with some thoughts about where the field seems to be heading. The book is organized into seven sections.

Part I: The Nature of Human Concepts

The three chapters in Part I address foundational issues related to the representation of human concepts. Chapter 2 by **Goldstone** and **Son** reviews work on the core concept of similarity – how people assess the degree to which objects or events are alike. Chapter 3 by **Medin** and **Rips** considers research on categories and how concepts are organized in semantic memory. Thinking depends not only on representations of individual concepts, such as dogs and cats, but also on representations of the relationships among concepts, such as the fact that dogs often chase cats. In Chapter 4, **Doumas** and **Hummel** evaluate different computational approaches to the representation of relations.

Part II: Reasoning

Chapters 5 to 10 deal with varieties of the core topic of reasoning. In Chapter 5, **Sloman** and **Lagnado** set the stage by laying out the issues surrounding induction – using what is known to generate plausible, although uncertain, inferences. Then, in Chapter 6, **Holyoak** reviews the literature on reasoning by analogy, an important variety of inductive reasoning that is critical for learning. The most classic aspect of induction is the way in which humans and other creatures acquire knowledge about causal relations, which is critical for predicting the consequences of actions and events. In Chapter 7, **Buehner** and **Cheng** discuss research and theory on causal learning. Then, in Chapter 8, **Evans** reviews work on the psychology of deductive reasoning, the form of thinking with the closest ties to logic. In Chapter 9, **Johnson-Laird** describes the work that he and others have performed using the framework of mental models to deal with various reasoning tasks, both deductive and inductive. Mental models have close connections to perceptual representations that are visuospatial in Chapter 10, Barbara **Tversky** reviews work on the role of visuospatial representations in thinking.

Part III: Judgment and Decision Making

We then turn to topics related to judgment and decision making. In Chapter 11, **LeBoeuf** and **Shafir** set the stage with a general review of work on decision making. Then, in Chapter 12, **Kahneman** and **Frederick** present an overarching model of heuristic judgment. In Chapter 13, **Molden** and **Higgins** review research revealing the ways in which human motivation and emotion influence judgment.

Part IV: Problem Solving and Complex Learning

The five chapters that comprise this section deal with problem solving and allied issues concerning how people learn in problem-solving situations. In Chapter 14, **Novick** and **Bassok** provide a general overview of the field of human problem solving. Problem solving has close connections to the topic of creativity, the focus of Chapter 15 by **Sternberg, Lubart, Kaufman**, and **Pretz**. Beyond relatively routine problem solving, there are occasions when people need to restructure their knowledge in complex ways to generate deeper understanding. How such complex learning takes place is the topic of Chapter 16 by **Chi** and **Ohlsson**. In Chapter 17, **Lovett** and **Anderson** review work on thinking that is based on a particular formal approach rooted in work on problem solving, namely, production systems. Finally, in Chapter 18, **Litman** and **Reber** consider research suggesting that some aspects of thinking and learning depend on implicit mechanisms that operate largely outside of awareness.

Part V: Cognitive and Neural Constraints on Human Thought

High-level human thinking cannot be fully understood in isolation from fundamental cognitive processes and their neural substrates. In Chapter 19, **Morrison** reviews the wealth of evidence indicating that thinking and reasoning depend critically on what is known as "working memory," that is, the system responsible for short-term maintenance and manipulation of information. Current work is making headway in linking thought processes to specific brain structures such as the prefrontal cortex; in Chapter 20, **Goel** discusses the key topic of deductive reasoning in relation to its neural substrate. Brain disorders, notably schizophrenia, produce striking disruptions of normal thought processes, which can shed light on how thinking takes place in normal brains. In Chapter 21, **Bachman** and **Cannon** review research and theory concerning thought disorder.

Part VI: Ontogeny, Phylogeny, Language, and Culture

Our understanding of thinking and reasoning would be gravely limited if we restricted investigation to young adult English speakers. The six chapters in Part VI deal with the multifaceted ways in which aspects of thinking vary across the human lifespan, across species, across speakers of different languages, and across cultures. In Chapter 22, **Halford** provides an overview of the development of thinking and reasoning over the course of childhood. In Chapter 23, **Gallistel** and **Gelman** discuss mathematical thinking, a special form of thinking found in rudimentary form in nonhuman animals that undergoes development in children. In Chapter 24, **Salthouse** describes the changes in thinking and reasoning brought on by the aging process. The phylogeny of thinking – thinking and reasoning as performed by apes and monkeys – is discussed in Chapter 25 by **Call** and **Tomasello**. One of the most controversial topics in the field is the relationship between thinking and the language spoken by the thinker; in Chapter 26, **Gleitman** and **Papafragou** review the hypotheses and evidence concerning the connections between language and thought. In Chapter 27, **Greenfield** considers the ways in which modes of thinking may vary in the context of different human cultures.

Part VII: Thinking in Practice

In cultures ancient and modern, thinking is put to particular use in special cultural practices. Moreover, there are individual differences in the nature and quality of human thinking. This section includes three chapters focusing on thinking in particular practices and two chapters that deal with variations in thinking ability. In Chapter 28, **Ellsworth** reviews what is known about thinking in the field of law. In Chapter 29, **Dunbar** and **Fugelsang** discuss thinking and reasoning as manifested in the practice of science. In Chapter 30, **Patel, Arocha**, and **Zhang** discuss reasoning in a field – medicine – in which accurate diagnosis and treatment are literally everyday matters of life and death. Then, in Chapter 31, **Sternberg** reviews work on the concept of intelligence as a source of individual differences in thinking and reasoning. Finally, Chapter 32 by **Ritchhart** and **Perkins** concludes the volume by reviewing one of the major challenges for education – finding ways to teach people to think more effectively.

Examples of Chapter Assignments for a Variety of Courses

This volume offers a comprehensive treatment of higher cognition. As such, it serves as an excellent source for courses on thinking and reasoning, both at the graduate level and for upper-level undergraduates. Although instructors for semester-length graduate courses in thinking and reasoning may opt to assign the entire volume as a textbook, there are a number of other possibilities (including using chapters from this volume as introductions for various topics and then supplementing with readings from the primary literature). Here are a few examples of possible chapter groupings tailored to a variety of possible course offerings:

Introduction to Thinking and Reasoning

Chapter 1	Thinking and Reasoning: A Reader's Guide
Chapter 2	Similarity
Chapter 3	Concepts and Categories: Memory, Meaning, and Metaphysics

Chapter 5	The Problem of Induction
Chapter 6	Analogy
Chapter 7	Causal Learning
Chapter 8	Deductive Reasoning
Chapter 9	Mental Models and Thought
Chapter 10	Visuospatial Reasoning
Chapter 11	Decision Making
Chapter 12	A Model of Heuristic Judgment
Chapter 14	Problem Solving
Chapter 15	Creativity
Chapter 16	Complex Declarative Learning
Chapter 18	Implicit Cognition and Thought

Development of Thinking

Chapter 2	Similarity
Chapter 3	Concepts and Categories: Memory, Meaning, and Metaphysics
Chapter 22	Development of Thinking
Chapter 23	Mathematical Thinking
Chapter 26	Language and Thought
Chapter 24	Effects of Aging on Reasoning
Chapter 25	Reasoning and Thinking in Nonhuman Primates
Chapter 19	Thinking in Working Memory
Chapter 31	Intelligence
Chapter 32	Learning to Think: The Challenges of Teaching Thinking

Modeling Human Thought

Chapter 2	Similarity
Chapter 3	Concepts and Categories: Memory, Meaning, and Metaphysics
Chapter 4	Approaches to Modeling Human Mental Representations: What Works, What Doesn't, and Why
Chapter 6	Analogy
Chapter 7	Causal Learning
Chapter 9	Mental Models and Thought
Chapter 22	Development of Thinking
Chapter 17	Thinking as a Production System

Applied Thought

Chapter 14	Problem Solving
Chapter 10	Visuospatial Reasoning
Chapter 23	Mathematical Thinking
Chapter 26	Language and Thought
Chapter 15	Creativity
Chapter 31	Intelligence
Chapter 13	Motivated Thinking
Chapter 27	Paradigms of Cultural Thought
Chapter 16	Complex Declarative Learning
Chapter 18	Implicit Cognition and Thought
Chapter 28	Legal Reasoning
Chapter 29	Scientific Thinking and Reasoning
Chapter 30	Reasoning in Medicine

Differences in Thought

Chapter 31	Intelligence
Chapter 15	Creativity
Chapter 19	Thinking in Working Memory
Chapter 21	Cognitive and Neuroscience Aspects of Thought Disorder
Chapter 22	Development of Thinking
Chapter 25	Reasoning and Thinking in Nonhuman Primates
Chapter 24	Effects of Aging on Reasoning
Chapter 26	Language and Thought
Chapter 13	Motivated Thinking
Chapter 27	Paradigms of Cultural Thought
Chapter 29	Scientific Thinking and Reasoning
Chapter 32	Learning to Think: The Challenges of Teaching Thinking

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Notes

1. Notice the linguistic connection between "thinking" and "seeing," and thought and perception, which was emphasized by the Gestalt psychologists of the early twentieth century.
2. The distinction between deduction and induction blurs in the study of the psychology of thinking, as we see in Part II of this volume.
3. There are echoes of the old meaning of "reckon" in such phrases as "reckon the cost." As a further aside, the term "dead reckoning," a procedure for calculating the position of a ship or aircraft, derives from "deductive reasoning." In an old Western movie, a hero in a tough spot might venture, "I reckon we can hold out till sun-up," illustrating how calculation has crossed over to become a metaphor for mental judgment.
4. See Johnson-Laird, Chap. 9, for a current view of thinking and reasoning that owes much to Craik's seminal ideas.
5. Indeed, Marr criticized Newell and Simon's approach to problem solving for paying insufficient attention to the computational level in his sense.

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