Introduction
The Challenge of Cognitive Science

Overview

Cognitive science draws upon the tools and techniques of many different disciplines, including psychology, philosophy, linguistics, computer science, neuroscience, mathematical logic . . . It is a fundamentally *interdisciplinary activity*. This basic fact raises important and fundamental questions. What do all these disciplines have in common? How can they all come together to form a distinctive area of inquiry?

The aim of this introduction is to give you a sense of the scope and range of cognitive science, setting the framework for more detailed study in subsequent chapters. We will explore the idea that the different disciplines in cognitive science each study different levels of organization in the mind and the nervous system. In particular, we will see how the brain can be studied at many different levels, from the level of the molecule upward. The introduction ends with a description (and illustration) of what I call the space of cognitive science.

0.1 Cognitive Science: An Interdisciplinary Endeavor

The hexagonal diagram in Figure 0.1 is one of the most famous images in cognitive science. It comes from the 1978 report on the state of the art in cognitive science commissioned by the Sloan Foundation and written by a group of leading scholars. The diagram is intended to illustrate the interdisciplinary nature of cognitive science. The lines on the diagram

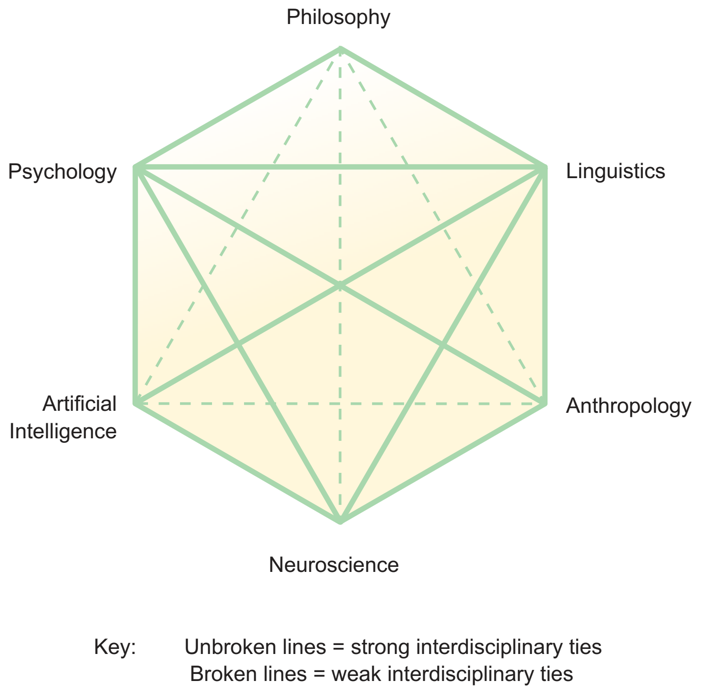

Figure 0.1 Connections among the cognitive sciences, as depicted in the Sloan Foundation's 1978 report. Unbroken lines indicate strong interdisciplinary links, while broken lines indicate weaker links. (Adapted from Gardner 1985)

indicate the academic disciplines that the authors saw as integral parts of cognitive science, together with the connections between disciplines particularly relevant to the study of mind and cognition.

For the authors of the Sloan report, cognitive science is an amalgamation of philosophy, psychology, linguistics, anthropology, neuroscience, and artificial intelligence. Each of the six disciplines brings with it different techniques, tools, and frameworks for thinking about the mind. Each of them studies the mind from different perspectives and at different levels. Whereas linguists, for example, develop abstract models of linguistic *competence* (the abstract structure of language), psychologists of language are interested in the mechanisms that make possible the *performance* of language users. Whereas neuroscientists study the details of how the brain works, computer scientists abstract away from those details to explore computer models and simulations of human cognitive abilities. Anthropologists are interested in the social dimensions of cognition, as well as how cognition varies across cultures. Philosophers, in contrast, are typically interested in very abstract models of how the mind is realized by the brain.

Some of the connections identified in the diagram were judged stronger than others. These are marked with a solid line. The weaker connections are marked with a broken line. At least one of the connections that was judged weak in 1978 has now become a thriving subdiscipline in its own right. A group of philosophers impressed by the potential for fruitful dialog between philosophy and neuroscience have taken to calling themselves neurophilosophers, after the title of a very influential book by Patricia Churchland published in 1986.

Miller's own account of how the Sloan report was written is both disarming and telling. "The committee met once, in Kansas City. It quickly became apparent that everyone knew his own field and had heard of two or three interesting findings in other fields. After hours of discussion, experts in discipline X grew unwilling to make any judgments about discipline Y, and so forth. In the end, they did what they were competent to do: each summarized his or her own field and the editors – Samuel Jay Keyser, Edward Walker and myself – patched together a report" (Miller 2003: 143). This may be how reports get written, but it is not a very good model for an interdisciplinary enterprise such as cognitive science.

In fact, the hexagon as a whole is not a very good model for cognitive science. Even if we take seriously the lines that mark connections between the disciplines of cognitive science, the hexagon gives no sense of a unified intellectual enterprise. It gives no sense, that is, of something that is more than a composite of "traditional" disciplines such as philosophy and psychology. There are many different schools of philosophy and many different specializations within psychology, but there are certain things that bind together philosophers as a group and psychologists as a group, irrespective of their school and specialization. For philosophers (particularly in the so-called *analytic* tradition, the tradition most relevant to cognitive science), the unity of their discipline comes from certain problems that are standardly accepted as philosophical, together with a commitment to rigorous argument and analysis. The unity of psychology comes, in contrast, from a shared set of experimental techniques and paradigms. Is there anything that can provide a similar unity for cognitive science?

One of the main claims of this textbook is that cognitive science is indeed a unified enterprise. It has its own distinctive problems. Its own distinctive techniques, And its own distinctive explanatory frameworks. We will be studying all of these in this book. First, though, we need to get a better picture of the range and scope of the enterprise. In the rest of this introduction I'll use psychology and neuroscience as examples to give you a sense of the overall space of cognitive science.

0.2 Levels of Explanation: The Contrast between Psychology and Neuroscience

Neuroscience occupies one pole of the Sloan report's hexagonal figure and it was not viewed as very central to cognitive science by the authors of the report. The report was written before the "turn to the brain" that we will look at in Chapter 3, and its focus reflected the contemporary focus on computer science, psychology, and linguistics as the core disciplines of cognitive science. Moreover, the authors of the report treated neuroscience as a unitary discipline, on a par with anthropology, psychology, and other more traditional academic disciplines. The explosion of research into what became known as cognitive neuroscience has since corrected both of these assumptions.

Most cognitive scientists place the study of the brain firmly at the heart of cognitive science. And it is becoming very clear that neuroscience is itself a massively interdisciplinary field.

How Psychology Is Organized

One way of thinking about what distinguishes neuroscience from, say, psychology is through the idea of levels. I am talking here about what is sometimes called scientific psychology (psychology as it is taught and studied in university departments), as opposed, for example, to humanistic psychology, self-help psychology, and much of what is routinely classified as psychology in bookstores. But even narrowing it down like this, there are many different subfields of psychology.

A quick look at the courses on offer in any reputable psychology department will find courses in cognitive psychology, social psychology, abnormal psychology, personality psychology, psychology of language, and so on. It is normal for research psychologists to specialize in at most one or two of these fields. Nonetheless, most psychologists think that psychology is a single academic discipline. This is partly because there is a continuity of methodology across the different specializations and subfields. Students in psychology are typically required to take a course in research methods. Such courses cover basic principles of experimental design, hypothesis formation and testing, and data analysis that are common to all branches of psychology.

Equally important, however, is the fact that many of these branches of psychology operate at the same level. The data from which they begin are data about cognitive performance and behavior at the level of the whole organism (I am talking about the whole organism to make clear that these ideas extend to nonhuman organisms, as studied in comparative psychology).

The basic *explananda* (the things that are to be explained) in psychology are people's psychological capacities, which includes both cognitive and emotional capacities. The organization of psychology into different subfields is a function of the fact that there are many different types of cognitive and emotional capacities.

Within cognitive psychology, for example, what psychologists are trying to explain are the organism's capacities for perception, memory, attention, and so on. Controlled experiments and correlational studies are used to delimit and describe those capacities, so that psychologists know exactly what it is that needs to be explained.

Likewise, social psychologists study the capacities involved in social understanding and social interactions. They are interested, for example, in social influences on behavior, on how we respond to social cues, and on how our thoughts and feelings are influenced by the presence of others. Personality psychologists study the traits and patterns of behavior that go to make up what we think of as a person's character. And so on.

If we were to map out some of the principal subfields in scientific psychology it would look something like Figure 0.2. The diagram is intended to show that the different sub-branches all study different aspects of mind and behavior at the level of the organism.

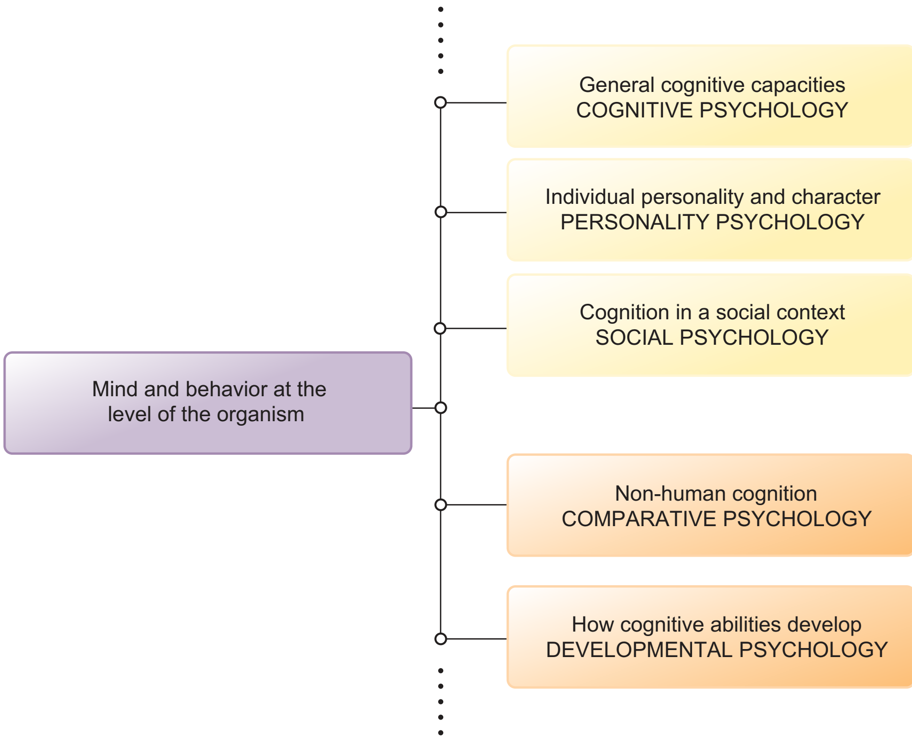

Figure 0.2 Some of the principal branches of scientific psychology.

How Neuroscience Is Organized

Things are very different in neuroscience. There are many branches of neuroscience, but they are not related in the same way. The organization of neuroscience into branches closely follows the different levels of organization in the brain and the central nervous system. These levels of organization are illustrated in Figure 0.3, drawn from Gordon Shepherd's 1994 textbook *Neurobiology*.

You may have come across references to areas in the brain such as the primary visual cortex or the hippocampus, for example. And you may have encountered talk of neural pathways connecting different areas in the brain. Located at levels A and B in Shepherd's diagram, these are the highest levels of neural organization, corresponding most closely to cognitive activities that we all perform. The primary visual cortex, for example, is responsible for coding the basic features of visual information coming from the retina. It is sensitive to orientation, motion, speed, direction, and so on. The hippocampus, in contrast, is thought to be responsible for key aspects of memory.

Activity at this top level of organization is the result of activity at lower levels of organization. In Shepherd's diagram this takes us to levels C and E – the level of centers, local circuits, and microcircuits. Somehow the collective activity of populations of neurons codes certain types of information about objects in a way that organizes and coordinates

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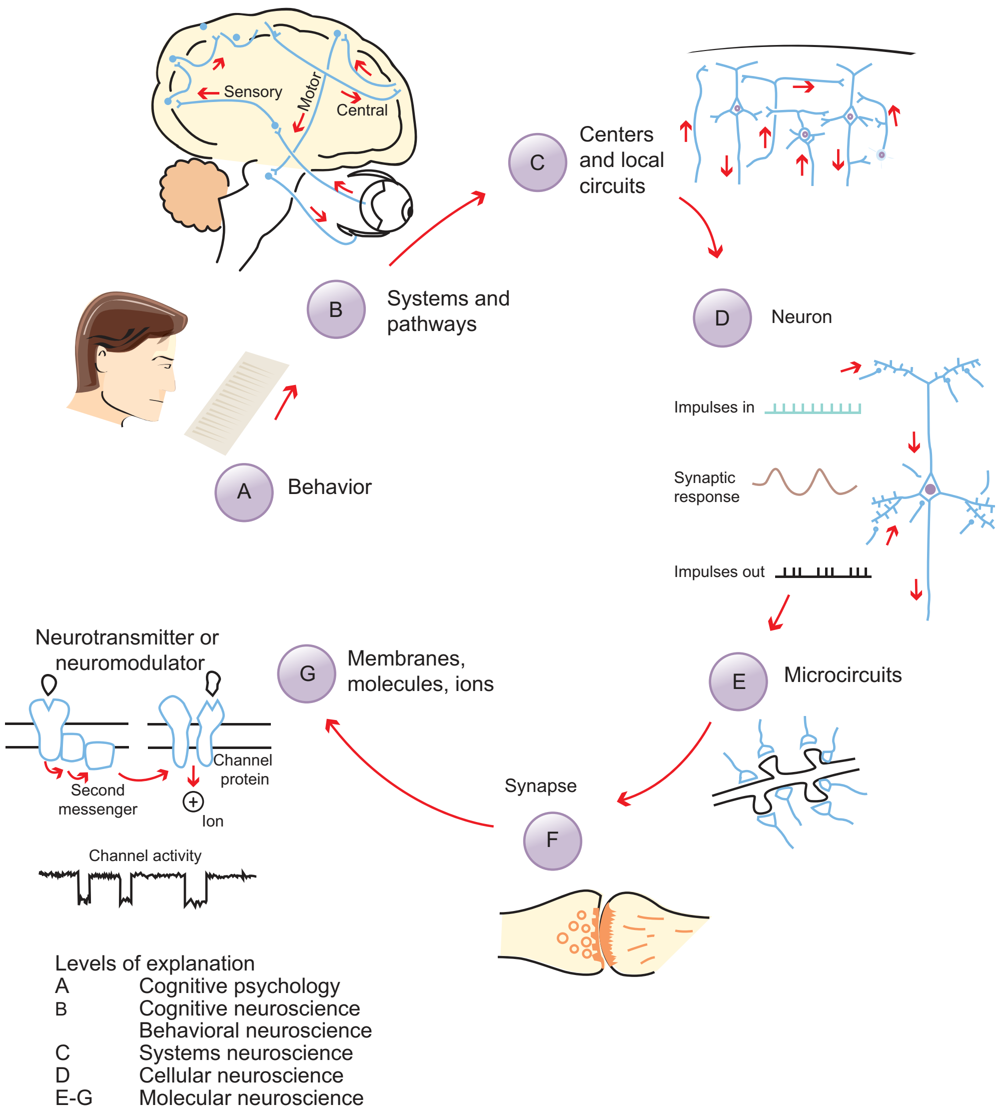

Figure 0.3 Levels of organization and levels of explanation in the nervous system. (Adapted from Shepherd 1994)

the information carried by individual neurons. These populations of neurons are the local circuits in Shepherd's diagram.

What happens in populations of neurons is ultimately determined by the behavior of individual neurons. But neurons are not the most basic level of organization in the nervous system. In order to understand how neurons work we need to understand how they communicate. This brings us to Shepherd's level F, because neurons communicate across synapses. Most synapses are chemical, but some are electrical. The chemical synapses work through the transmission of neurochemicals (*neurotransmitters*). These neurotransmitters are activated by the arrival of an electrical signal (the *action potential*). The propagation of neurotransmitters works the way it does because of the molecular properties of the synaptic membrane – properties that are ultimately genetically determined. With this we arrive at level G in Shepherd's diagram.

The point of this whistle-stop tour through the levels of organization in the brain is that the subfields of neuroscience map very closely onto the different levels of organization in the brain. At the top level we have cognitive neuroscience and behavioral neuroscience, which study the large-scale organization of the brain circuits deployed in high-level cognitive activities. These operate at what in discussing the subfields of psychology I termed the level of the whole organism. Systems neuroscience, in contrast, investigates the functioning of neural systems, such as the visual system. The bridge between the activity of neural systems and the activity of individual neurons is one of the central topics in computational neuroscience, while cellular and molecular neuroscience deal with the fundamental biological properties of neurons.

Different branches of neuroscience (and cognitive science in general) employ tools appropriate to the level of organization at which they are studying the brain. These tools and techniques vary in what neuroscientists call their temporal and spatial resolution. That is, they vary in the scale on which they give precise measurements (spatial resolution) and the time intervals to which they are sensitive (temporal resolution).

Some of the important variations are depicted in Figure 0.4. We will explore the differences between these different tools and technologies in much more detail in later chapters (particularly Chapter 9).

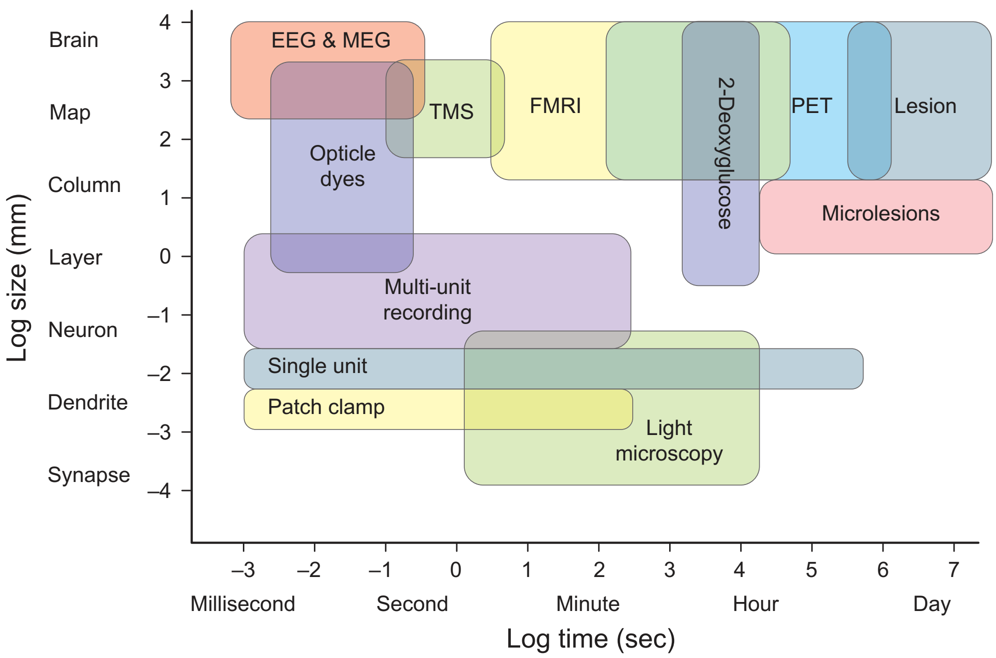

Figure 0.4 The spatial and temporal resolution of different tools and techniques in neuroscience. Time is on the *x*-axis and size is on the *y*-axis. (Adapted from Baars and Gage 2010)

0.3 The Challenge of Cognitive Science

This section explores these basic ideas of levels of organization, levels of resolution, and levels of explanation further, to give a picture of what I call the space of cognitive science.

Three Dimensions of Variation

Cognitive science draws upon a large number of potentially relevant fields and subfields. Those fields and subfields differ from each other along three dimensions.

One dimension of variation is illustrated by the subfields of neuroscience. Neuroscience studies the brain at many different levels. These levels are organized into a vertical hierarchy that corresponds to the different levels of organization in the nervous system.

A second dimension of variation comes with the different techniques and tools that cognitive scientists can employ. As illustrated in Figure 0.4, these tools vary both in spatial and in temporal resolution. Some tools, such as PET and fMRI, give accurate measurements at the level of individual brain areas. Others, such as microelectrode recording, give accurate measurements at the level of individual neurons (or small populations of neurons).

The third dimension of variation is exemplified by the different subfields of psychology. Most of psychology operates at Shepherd's level A. The different areas of psychology set out to explore, map, describe, and explain are the cognitive abilities making possible the myriad things that human beings do and say.

The Space of Cognitive Science

The different parts of cognitive science are distributed, therefore, across a three-dimensional space illustrated in Figure 0.5.

- The *x*-axis marks the different cognitive domains that are being studied
- The *y*-axis marks the different tools that might be employed (ordered roughly in terms of their degree of spatial resolution).
- The *z*-axis marks the different levels of organization at which cognition is studied.

This three-dimensional diagram is a more accurate representation of where cognitive science stands in the early years of the twenty-first century than the two-dimensional hexagon proposed by the authors of the Sloan report (although the hexagon may well have been an adequate picture of how things stood at the end of the 1970s).

A good way of thinking about cognitive science is as setting out to provide a unified account of cognition that draws upon and integrates the whole space. Cognitive science is more than just the sum of its parts. The aim of cognitive science as an intellectual enterprise is to provide a framework that makes explicit the common ground between all the different academic disciplines that study the mind and that shows how they are related to each other.

You can think of the analogy with physics. Many theoretical physicists think that the ultimate goal of physics is to provide a unified Theory of Everything. So too (on this way of thinking about cognitive science) is it the mission of cognitive science to provide a unified Theory of Cognition.

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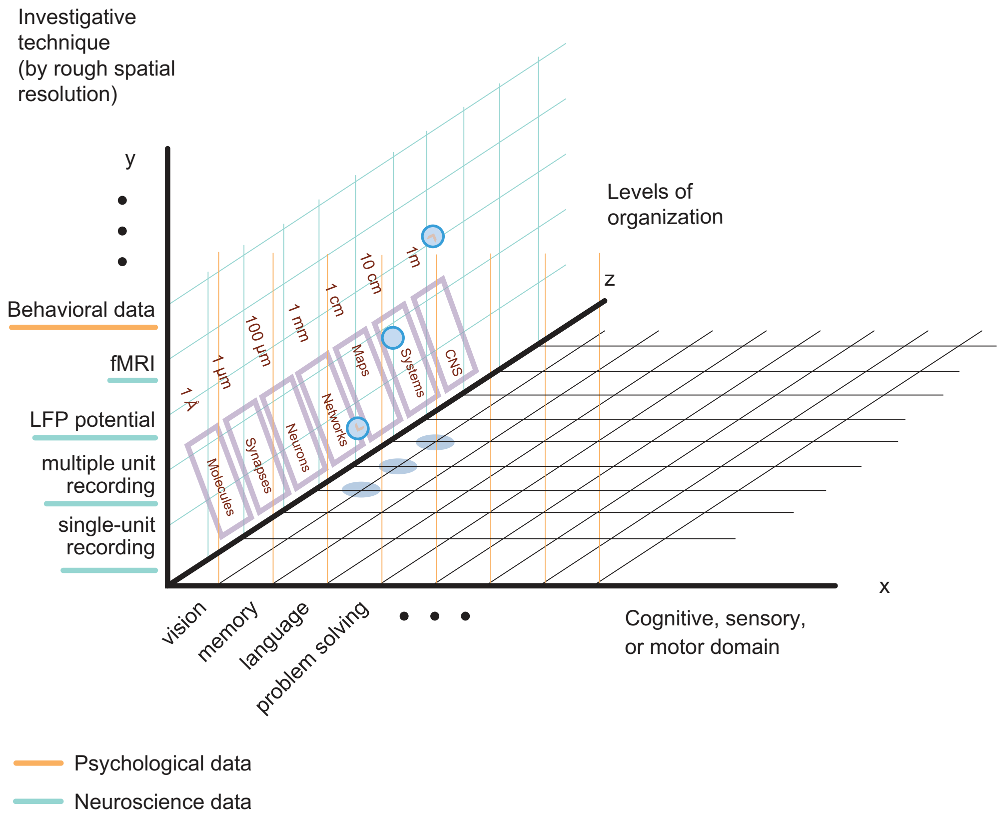

Figure 0.5 The "space" of contemporary cognitive science.

Parts II and III will explore the principal theories of cognition in cognitive science, and see how they can be applied to explain different aspects of cognition. First, though, we turn to an overview of some of the key historical landmarks in the emergence and subsequent development of cognitive science. That will occupy the three chapters of Part I. These chapters should put flesh on the bones of the general picture sketched out in this introduction.

Further Reading

Historical background on the Sloan report can be found in Gardner 1985 and Miller 2003 (available in the online resources). The report itself was never published. A very useful basic introduction to levels of organization and structure in the nervous system is chapter 2 of Churchland and Sejnowski 1992. For more detail, a classic neuroscience textbook is Kandel, Schwarz, and Jessell 2012. Stein and Stoodley 2006 and Purves et al. 2011 are alternatives. Craver 2007 discusses the interplay between different levels of explanation in the neuroscience of memory. Piccinini and Craver 2011 is a more general discussion; also see Bickle 2006 and Sullivan 2009.