12 Bodies, the World, and Dynamic Systems

The three challenges (body, world, and dynamic systems) discussed in this chapter accuse CRUM of focusing too much on mental representation and neglecting the fact that thought is not a solitary, disembodied occurrence, but rather occurs in individuals who interact with a physical world. Extreme versions of these challenges totally reject the idea of mental representation, claiming that human intelligence is a matter of bodies inhabiting physical environments and operating in them in ways that are not at all like how a computer processes information. I have grouped together diverse criticisms concerning bodies and the world, and tried to give a common set of responses. This chapter also considers whether it is useful to think of the mind as a dynamic system of the sort commonly investigated in physics and biology.

Bodies in the World

The core idea behind the body and world challenges is that thinking is not just in the head. CRUM seems to restrict thinking to computational processing occurring in the mind, ignoring the fact that most of what people do involves continuous and rich interaction between both their bodies and the world-at-large. There are diverse variants of the objection that CRUM neglects the body and the world, including psychologists who tie concepts closely to direct perception, philosophers influenced by Martin Heidegger, and researchers in robotics disaffected with standard approaches to artificial intelligence.

Embodiment and Direct Perception

How do people interact with the world? Information needs to be conveyed from the world to the mind through the senses. CRUM treats perception as involving the inferential construction of representations that capture features of the world. Psychologists influenced by Gibson (1979) have rejected this inferential view of perception and claimed that we learn about the world more directly, by having our perceptual apparatus so attuned to the world that information is directly conveyed to the brain without requiring computations on representations. Our physical sensory apparatus is one of the contributors to our ability to interact with the world.

As we saw in the discussion of emotions, CRUM tends to treat the nature of our bodies as largely irrelevant to our cognitive processes. But Johnson (1987) and Lakoff (1987) have argued that this tradition has neglected the crucial role that our bodies play in our thinking. Many of the metaphors that permeate our language derive from body-based relations such as up and down, left and right, and in and out. If we did not have the kinds of bodies we have, operating in the kind of world we inhabit, then our systems of metaphor and our whole mental apparatus would be different from what they are. It may seem to be a virtue of CRUM that it potentially applies to computers and extraterrestrial beings independent of physical makeup, but this virtue is illusory if in fact many of the key aspects of human thinking depend on the kind of body we have and how it is attuned to the world.

Lakoff and Johnson (1999) argue that human concepts are embodied in the sense that they are crucially shaped by our bodies and brains, especially by our sensory and motor systems. For example, our concepts of color are shaped in part by two aspects of our bodies: the color cones in our retinas that absorb light of different wavelengths, and the complex neural circuitry connected to those cones. Moreover, the basic concepts that we use to categorize the world are derived in part from the way that our visual and other sensory systems detect the overall part-whole structure of the world. We can form visual images of elephant and chairs, but not of more abstract concepts such as *animal* and *furniture*. Concepts of spatial relations such as *above*, *in front of*, and *contains* are also deeply affected by the ways that our bodies perceive and react to the world. Barsalou et al. (2003) review evidence from psychological and neurological experiments that support the view that conceptual representations are grounded in specific sensory modalities. For example, your representation of a car is not an abstract, verbal symbol like the concepts in chapter 4, but rather involves neurons in the brain's visual areas that capture and reenact sensory experiences of cars.

Being-in-the-World

How do people hammer in a nail? To answer this question from the perspective of CRUM, we would start to consider what kinds of representation we have of a hammer and a nail. For each of these, we perhaps have a concept or image that we use to represent hammers and nails, and our hammering takes place because we are able to do computational operations on these representations that somehow get translated into the physical action of hammering the nail.

The German philosopher Heidegger rejected this representational view of the practice of hammering (1962; Dreyfus 1991). He denied the division assumed in cognitive science between the representing subject and the world, and claimed that we function in the world simply because we are a part of it. He used the expression "being-in-the-world" to convey that people can perform tasks like hammering just by virtue of their physical skills, without any kinds of representation. Dreyfus (1992) mounted Heideggerian arguments against artificial intelligence, claiming that its attempt to formalize and represent knowledge is hopeless, because our intelligence is inherently nonrepresentational.

The antirepresentational view of cognition has found favor in some AI researchers who have become disaffected with the standard approach. Winograd and Flores (1986) endorse a Heideggerian perspective and conclude that the standard approach to AI is impossible, because we will never be able to represent the mass of background information underlying human performance. Smith (1991) advocates what he calls "embedded computing," which avoids the representational load of traditional computational approaches by emphasizing interaction with the world rather than internal processing. Similarly, Dourish (2001) claims that attention to embodied interaction can lead to the design of more effective interactive computers.

Robotics

Embodiment has also been a major theme in research in robotics. Brooks (1991, 2002) has advocated an approach to building robots that is very different from that of researchers in the logic and rule-based traditions. Instead of trying to encode the knowledge that a high-level robot needs to have to plan its movements around its environment, he builds simple machines that have the capacity to learn about their environments. Rather than encoding complex rules about how to walk, Brooks gives his insect-like robots multiple processors that enable them to learn to walk by interacting with the environment, without using any of the representation techniques advocated by the six approaches to CRUM discussed in earlier chapters. The humanoid robots that Brooks and his students have built are designed to be able to recognize and respond to faces, but contain no concepts or rules for reasoning about people. Mackworth (1993) has also advised building robots that are physical systems embedded in the real world, closely coupling perception and action. He has built a system of mobile robots that rapidly play a simple version of soccer without the complex representations and plans usually used in robots based on artificial intelligence.

Situated Action

Some anthropologists and psychologists have also argued that cognitive science has erred in overemphasizing the mental and underemphasizing the role that situations and context play in human problem solving and learning. Suchman (1987) and Lave and Wenger (1991) contend that cognitive psychologists have examined human thinking on artificial tasks, and that problem solving in realistic contexts is not so heavily dependent on mental representation, but rather depends on direct interaction with the world and other people. People who lack abstract mathematical representations can nevertheless perform more than adequately at practical tasks such as dividing a pizza up at a party. Using a complex machine like a computer is not just a matter of forming an abstract representation of it, but rather of learning how to interact with it. Suchman and Lave see people, like Brooks's simple robots, as thinking through interaction with the world rather than by means of representing it and processing those representations. Shanon (1993) argues that CRUM is incapable of appreciating the subtle, contextual ways in which people deal with the world.

Intentionality

The relation between mind and world is also involved in what philosophers such as John Searle (1992) see as a crucial objection to CRUM. Mental states are intended to represent the world: they possess intentionality, the property of being *about* something. Your belief that your friends are at the library is not simply a representation in your head; it is about your friends and the library, which are parts of the world. Searle uses a thought experiment to contend that a computer could never have intentionality. Imagine that you are locked in a room and people pass you paper with symbols that you do not recognize. You are, however, able to use a whole set of tables to look up the symbols given to you and select other symbols that you then pass back out of the room. Unknown to you, the symbols are Chinese, and when you pass back the symbols you have looked up, you are providing sensible answers to questions that you received. Searle contends that it is obvious that you are merely manipulating symbols you do not understand, so that similarly a computer manipulating symbols is lacking in understanding. The symbols that people operate with have the semantic property of intentionality based on our interactions with the world, but representations in computers are independent of the world and therefore lacking in intentionality. Computers are purely syntactic engines lacking human semantic capabilities that provide meaning to their symbols based on their interactions with the world. Therefore, the computational view of mind is fundamentally flawed.

Responses to the Body and World Challenges

Denial

Can cognitive science ignore bodies and the world? Although CRUM has focused on representations and processes rather than on physical interaction, CRUM should not simply deny the world challenge. Researchers in psychology and artificial intelligence sometimes use the term "representation" to mean nothing more than "structure," but a structure is a representation only if its purpose is to stand for something.

When people solve problems and learn, they are not operating as disembodied computers unconnected with the world. Computational models developed to date have tended to ignore the details of physical environments. Most computers used in modeling have no connection with the world other than the keyboards that programmers use to type instructions. Greater appreciation of the structure of the world is important for helping designers to produce machines and tools that people can easily use (Norman 1989). Hence, CRUM needs to be expanded and supplemented to encompass the body and the world. Radical proponents of being-in-the-world, embedded computing, situated action, and intentionality will see this expansion as a waste of time, on the grounds that CRUM is utterly misguided. But CRUM's explanatory accomplishments justify asking how the body and world challenges might be met. Heideggerians may say that we do not represent the world, we just embody it, but these may not be exclusive alternatives.

Expand CRUM

As we saw in chapters 9–11, neuroscience, emotions, and consciousness suggest the need for expanding the range of representations CRUM considers beyond the standard ones in chapters 2–7. Similarly, taking the world and the body seriously suggests the need for new sorts of representations. When I see a house on top of a hill, the linguistic encoding *on* (*house, hill*) does not capture all the knowledge that my perceptual experience has given me. Imagistic representations should include not only the visual images discussed in chapter 6, but also images derived from the other sensory modalities of smell, taste, hearing, and touch. Hammering a nail is not just a matter of representing the concepts of hammer and nail; it is also a matter of representing the kinesthetic feel of an arm doing the hammering. Abstracted from physical and neurological considerations, however, this kind of expansion of CRUM goes only a small way toward giving CRUM the capacity to explain interactions with the world.

Supplement CRUM

Just as the structure and operations of the brain and body matter for understanding emotions, so biological matters seem relevant to any full account of interactions with the world. A possible model for such investigations is Kosslyn's (1994b) work on imagery, where visual representations are described in connection with how the brain processes them. Similarly, we can hope to learn how the brain deals with other kinds of sensory input, and at least speculate about how these tie in with our verbal representations. Not all brain processes need be thought of in computational terms: see later in this chapter for a discussion of the brain as dynamic system. But a fully integrated account of human thinking will have be able to tie together the nonrepresentational operations of the brain and body with the computational procedures that seem crucial for high-level cognition. If some proponents of CRUM have been guilty of neglecting the facts that we can walk and throw and hammer, some environmental challengers have unfortunately threatened to reduce human thought either to simplistic, insectlike responses or to mysterious, unanalyzed occurrences.

Abandon CRUM

But if we add neuroscience into the picture, why do we need CRUM? Why not drop it out of the picture as an unnecessary middle layer of explanation between the world and the neural networks in the brain? The answer lies in the extraordinary complexity and diversity of human problem solving. Brooks's insectlike robots are very impressive in their ability to learn to scurry around their environments, but they are completely lacking in the capacity for higher-level planning such as people perform whenever they figure out how to get to another city. Similarly, being situated is a great boon for simple tasks, but people can solve complex, abstract tasks that go far beyond mere response to the environment. Images, concepts, rules and other representations enable us to carry out imaginary manipulations of the world that can take place independently of actual manipulations.

The intentionality problem is serious, but it is not beyond the range of a suitably enriched CRUM. We must grant that the desktop computers currently used to simulate thinking are syntactic engines that lack semantics: the fact that I can write "beer" in my computer program does not mean that my computer understands what a beer is. But computers are already being provided with limited capacities to learn about the world, by means of robotic interfaces that provide visual, auditory, and tactile input from the world, and by means of learning algorithms that can generate various kinds of distributed, verbal, or imagistic representations. Searle's Chinese room pumps your intuitions by making you see yourself as a disconnected symbol pusher. But if you are effective in processing Chinese symbols because you are part of a whole system that interacts with the world and thereby acquires the symbols in the lookup table, then you, together with the whole apparatus you employ, would naturally be judged to understand Chinese. Similarly, a robotic learning computer could have semantics to go with its syntax, and acquire intentionality for its internal representations. To provide a full model of human thinking, CRUM needs to take the world and our bodily interactions with it more seriously, but the required extensions are possible and natural. The theory of dynamic systems contains useful ideas for developing these extensions.

Dynamic Systems

The summary to chapter 1 presented the explanation schema central to CRUM, and the summaries to chapters 2–7 instantiated the schema with specific kinds of representations and processes. Many scientific explanations do not use this kind of explanation pattern. Suppose we want to explain why it rained yesterday. No respectable meteorologist would talk about the beliefs or the goals of the clouds and the raindrops, which are entities that simply do not have mental representations. Instead, meteorologists make their predictions and explanations by considering a large number of variables, including temperature, humidity, and air pressure at various locations. They incorporate these variables into mathematical equations that describe how the weather system changes over time. Meteorologists treat weather as a *dynamic system*, that is, as a system whose changes over time can be characterized by a set of equations that show how current values of variables depend mathematically on previous values of those variables.

Many phenomena in physics, biology, and even economics can usefully be understood in terms of dynamic systems ideas such as state space, attractors, phase transitions, and chaos. The *state space* of a system is the set of states it can be in as determined by the variables that are used to measure it. For example, a very simple weather model that keeps track of temperature, humidity, and air pressure at five locations has a total of fifteen variables, so all the different combinations of values of these variables constitute the state space of the system. Changes in the system can be described in terms of movement from one point in the space (one combination of values of all the variables) to another. Before fast computers existed, scientists could deal only with simple systems whose changes are describable by linear equations, those of the form $y = kx + c$. In this equation, the value of the variable y depends only on the value of the variable x multiplied by a constant k and added to a constant c. But complex dynamic systems need to be described by nonlinear equations such as $y = xz$, where the value of the variable y depends on interaction of values of x and z.

Nonlinear systems can have very erratic behavior, jumping from one point in the state space to another, very different point in a short period of time. The weather, for example, can change dramatically in a couple of hours with high winds and dropping temperatures when a cold front moves in. Despite these dramatic changes, dynamic systems may have relatively stable states called *attractors* that they tend to settle into. A system may have multiple attractors, so that there is more than one stable state. Change from one attractor state to another constitutes a *phase transition*, as when the weather moves from being cool and clear to being hot and humid, or when water gets cold enough that it freezes. In both these cases, what appear to be small local changes put the system into a qualitatively very different state.

A dynamic system displays *chaos* if it is very sensitive to initial conditions, that is, if very small differences in values of variables of its equations can produce dramatically different outcomes as the system develops. The weather is a chaotic system, since very small changes in variables far from some location can over time add up to dramatic changes in the weather there. This is called the butterfly effect: a butterfly flapping its wings in China may have a tiny effect on the atmospheric system there that eventually leads to a major weather change elsewhere. Chaotic systems can display abrupt changes (phase transitions) that are very hard to predict because they depend on minuscule changes in many variables. One of the reasons that the weather is very hard to predict more than a few days in advance is that meteorologists cannot measure all the slight differences in all the variables that affect the weather a few days in the future.

The dynamic systems challenge to cognitive science consists of the claim that, rather than understanding human thinking in computational-representational terms, we should think of the mind as a dynamic system. Instead of proposing a set of representations and processes, we should follow the successful example of physics and biology and try to develop equations that describe how the mind changes over time. Here is an explanation schema that employs some dynamic systems ideas:

Explanation Target

Why do people have **stable** but **unpredictable patterns of behavior**?

Explanatory Pattern

Human thought is describable by a set of **variables**.
These variables are governed by a set of nonlinear **equations**.
These **equations** establish a **state space** that has **attractors**.
The system described by the **equations** is **chaotic**.

The existence of the **attractors** explains **stable patterns** of behavior.
Multiple attractors explain abrupt **phase transitions**.
The **chaotic** nature of the system explains why **behavior** is **unpredictable**.

The plausibility of the dynamic systems challenge depends on the extent to which explanation schemas like this can be applied to make sense of many aspects of human thinking.

Application of dynamic systems concepts to cognition is relatively recent: most work has been published only since the 1990s. There are three different ways in which the mind has been viewed as a dynamic system. Relatively rare are cases where the explanation pattern that is so powerful in physics and biology is directly applied to cognition. It is very difficult in psychology to identify a small number of relevant variables and write equations using them that predict anything interesting. Nevertheless, dynamic systems accounts using small sets of variables and equations have been proposed for such phenomena as decision making (Busemeyer and Townsend 1993; Richards 1990) and language growth (van Geert 1991).

More commonly, researchers use dynamic systems ideas metaphorically when they cannot specify variables and equations. Even if these are unknown, it is still possible to describe changes in a complex system in terms of changes in state space, attractors, phase transitions, and chaos. Thelen and Smith (1994) interpret children's development in learning to walk in terms of transitions between attractor states. Other metaphorical applications of dynamic systems ideas have been made to clinical psychology (Barton 1994; Schmid 1991). Thagard and Nerb (2002) show how easy it is to apply dynamic systems ideas to emotions, which seem to be chaotic in the sense that small changes in your situation—for example, being insulted—can produce large changes in your emotional state and mood. On the other hand, the emotional dynamic system does have some stability, as people maintain a cheerful or terrible mood over long periods. This stability exists because the system has a tendency to evolve into a small number of general states called attractors, and the shift from one mood to another can be described as the shift from one attractor to another.

The third kind of application of dynamic systems ideas has been made by some connectionists who find describing the behavior of artificial and real neural networks in dynamic systems terms very useful. Connectionist systems are clearly dynamic systems in that they contain variables for the activations of the various units and for the strengths of the links between them, along with nonlinear equations for updating these activations and changing strengths. Connectionist dynamic systems differ from the first kind listed above in that the number of variables can be very large, since for every unit there is a separate variable representing its activation value. Concepts like attractors, phase transitions, and chaos can be shown to apply to neural networks: for example, when a network settles, it acquires a stable state in which no further activation changes occur. Connectionist models described in dynamic systems terms include those of Pollack (1991) and Skarda and Freeman (1987).

Responses to the Dynamic Systems Challenge

Denial

A defender of CRUM could argue that the dynamic systems approach is very limited in its application to human thinking. Although that approach has been powerful in physics and biology, the identification of small numbers of variables linked by small numbers of equations that has worked there has not so far been very useful in psychology. Instead, there has been a proliferation of metaphorical applications of dynamic systems ideas that have yielded very little in the way of precise predictions and modeling. Connectionist models have been more precise, but connectionism is part of CRUM, not an alternative to it; so dynamic systems theory is best seen as just an adjunct to connectionism rather than as an alternative to CRUM. Each of the three ways of applying dynamic systems ideas to thinking displays a limitation of this approach: human thinking is not subject to description in terms of a small number of variables, metaphorical explanation is of limited use, and connectionism does fine with only a minimal application of dynamic systems ideas.

Expand and Supplement CRUM

The dynamic systems approach should be taken more seriously than this argument suggests, since it embodies several aspects that are relatively neglected in the CRUM approach. First, as van Gelder and Port (1995) argue, the dynamic systems approach deals with time more gracefully than CRUM typically does. It provides a new set of ideas for describing changes that may occur in intelligent systems. Second, the dynamic systems approach provides a possible way of meeting the world challenge discussed earlier in this chapter. We saw that CRUM must face the problem that minds are not disembodied processors but must interact with a changing world. From a dynamic systems perspective, the mind and the world are not distinct, but together comprise one big dynamic system. Writing the equations to describe the interactions of mind and world is obviously very difficult, but at least mind and world are treated in comparable terms. Third, the dynamic systems approach might be useful for explaining non-representational aspects of human behavior. Even if problem solving and language are best understood in terms of mental representations, there are other aspects of human behavior such as motor control, moods, and sleep that are more naturally explained using dynamic systems ideas. When a two-year-old changes in seconds from smiling to screaming prompted by some tiny event, there is more to the dramatic behavioral shift than processing involving rules, concepts, analogies, images, or distributed representations. Emotional shifts, and other changes like a child's first steps or a person falling asleep, may be best understood in terms of a dynamic system possessing attractors and phase transitions.

Thus, CRUM, particularly its connectionist version, seems open to expansion and supplementation with dynamic systems ideas. The hypothesis that mind is a dynamic system is not yet a credible alternative to CRUM, since there is so much about problem solving, learning, and language that is explainable with CRUM and that proponents of the dynamic systems approach have not even addressed. Nevertheless, a full account of the nature of mind that incorporates human biology and interactions with the world may find it useful to draw on dynamic systems explanations. Eliasmith (2003) provides a plausible account of how to integrate symbolic, connectionist, and dynamic systems explanations of how the mind works.

Summary

According to the body and world challenges, cognitive science has not taken seriously enough the relation of minds to their physical environment. These challenges arise both in an abstract form (the problem of intentionality, which concerns how representations can be about the world) and in concrete psychological and computational forms. Some critics of CRUM have argued that our minds do not have to represent the world because they are situated in it. Although CRUM needs to be expanded and supplemented to better describe how thinking depends on interactions with the world, views of mind that emphasize the environment to the exclusion of the representational are not rich enough to account for the full range of human intelligent performance.

Instead of thinking of the mind as a computational-representational system, we might consider it as a dynamic system in which changes can be described by mathematical equations. Dynamic systems models of mind are relatively new, and fall into three classes that either use a small number of variables and equations, use dynamic systems ideas metaphorically, or use connectionist models described in dynamic systems terms. The dynamic systems approach seems promising for dealing with temporal, physical, and nonrepresentational aspects of mind, but suggests expanding and supplementing CRUM rather than abandoning it.

Discussion Questions

1. How much of driving a car involves mental representations, and how much is just knowing how to interact with the world?
2. Could a computer acquire intentionality?
3. Do computer models of the mind have to ignore the physical context of action?
4. What are the advantages of thinking of the mind as a dynamic system?
5. Is the dynamic systems approach incompatible with CRUM?
6. Are connectionist networks dynamic systems?

Further Reading

Clark 1997 discusses embodied and situated cognition; a briefer review is Clark 1999. On situated cognition, see Kirshner and Whitson 1997. The journal *Cognitive Science* had a special issue on situated action in January 1993, containing aggressive arguments for and against. Dietrich 1994 contains essays defending computational approaches to mind against various objections including intentionality.

Ward 2002 provides an introduction to dynamic cognitive science. See also Bechtel and Abrahamsen 2002. For a popular introduction to dynamic systems, see Gleick 1987. Abraham and Shaw 1992 gives a more rigorous introduction with applications to psychology. Works that argue for the dynamic systems approach to cognition include Thelen and Smith 1994 and Port and van Gelder 1995.

Web Sites

Dynamic systems research groups: http://www-chaos.umd.edu/nonlinear_sites.html

Embodied cognition links: http://www.geocities.com/fastiland/embodiment.html

Robotics frequently asked questions: http://www.frc.ri.cmu.edu/robotics-faq/TOC.html

Rodney Brooks's Web site: http://www.ai.mit.edu/people/brooks/index.shtml

Situated learning course: http://inkido.indiana.edu/syllabi/R695/sitcog.html

Notes

There has been much philosophical discussion of the problem of how representations represent. One issue concerns externalism, the extent to which content is determined by the external world. Von Eckardt 1993 contains a good discussion of recent views on content determination. I argued in chapter 4 that the meaning of concepts is a matter both of their relation to each other and of their relation to the world.

Dynamic systems are usually described using differential or difference equations. For example, consider the logistic difference equation

$$x_{t+1} = r * x_t * (1 - x_t).$$

We can interpret x_t as population at time t, a proportion of what is possible, and interpret r as rate of population growth. This simple equation displays very odd behavior: for r less than 1, the population goes to 1. For r between 1 and 3.57, the population is stable or oscillating between two points. For r greater than 3.57, the performance is chaotic, producing apparently random results, extremely dependent on the starting value of x. On your computer or calculator, see the difference between starting with $x = 0.4$ and starting with $x = 0.35$.