Cognitive Architecture: How Your Mind Functions Like Code

Authored by
mohammad looti

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Representation and Computation in Cognitive Psychology

The central hypothesis of Cognitive Psychology is that thinking can best be understood in terms of representational structures in the mind and computational procedures that operate on those structures. While there is much disagreement about the nature of the representations and computations that constitute thinking, the central hypothesis is general enough to encompass the current range of thinking in Cognitive Psychology, including connectionist theories which model thinking using artificial neural networks.

Most work in Cognitive Psychology assumes that the mind has mental representations analogous to computer data structures, and computational procedures similar to computational algorithms. Cognitive theorists have proposed that the mind contains such mental representations as logical propositions, rules, concepts, images, and analogies, and that it uses mental procedures such as deduction, search, matching, rotating, and retrieval. The dominant mind-computer analogy in Cognitive Psychology has taken on a novel twist from the use of another analog, the brain.

Connectionists have proposed novel ideas about representation and computation that use neurons and their connections as inspirations for data structures, and neuron firing and spreading activation as inspirations for algorithms. Cognitive Psychology then works with a complex 3-way analogy among the mind, the brain, and computers. Mind, brain, and computation can each be used to suggest new ideas about the others. There is no single computational model of mind, since different kinds of computers and programming approaches suggest different ways in which the mind might work. The computers that most of us work with today are serial processors, performing one instruction at a time, but the brain and some recently developed computers are parallel processors, capable of doing many operations at once.

Here is a schematic summary of current theories about the nature of the representations and computations that explain how the mind works.

Formal logic

Formal logic provides some powerful tools for looking at the nature of representation and computation. Propositional and predicate calculus serve to express many complex kinds of knowledge, and many inferences can be understood in terms of logical deduction with inferences rules such as modus ponens. The explanation schema for the logical approach is:

Explanation target:
• Why do people make the inferences they do?

Explanatory pattern:
• People have mental representations similar to sentences in predicate logic.

• People have deductive and inductive procedures that operate on those sentences.
• The deductive and inductive procedures, applied to the sentences, produce the inferences.

It is not certain, however, that logic provides the core ideas about representation and computation needed for Cognitive Psychology, since more efficient and psychologically natural methods of computation may be needed to explain human thinking.

Rules

Much of human knowledge is naturally described in terms of rules of the form IF ... THEN ..., and many kinds of thinking such as planning can be modeled by rule-based systems. The explanation schema used is:

Explanation target:
• Why do people have a particular kind of intelligent behavior?

Explanatory pattern:
• People have mental rules.
• People have procedures for using these rules to search a space of possible solutions, and procedures for generating new rules.
• Procedures for using and forming rules produce the behavior.

Computational models based on rules have provided detailed simulations of a wide range of psychological experiments, from cryptarithmetic problem solving to skill acquisition to language use. Rule-based systems have also been of practical importance in suggesting how to improve learning and how to develop intelligent machine systems.

Concepts

Concepts, which partly correspond to the words in spoken and written language, are an important kind of mental representation. There are computational and psychological reasons for abandoning the classical view that concepts have strict definitions. Instead, concepts can be viewed as sets of typical features. Concept application is then a matter of getting an approximate match between concepts and the world. Schemas and scripts are more complex than concepts that correspond to words, but they are similar in that they consist of bundles of features that can be matched and applied to new situations. The explanatory schema used in concept-based systems is:

Explanatory target:
• Why do people have a particular kind of intelligent behavior?

Explanation pattern:

• People have a set of concepts, organized via slots that establish kind and part hierarchies and other associations.
• People have a set of procedures for concept application, including spreading activation, matching, and inheritance.
• The procedures applied to the concepts produce the behavior.
• Concepts can be translated into rules, but they bundle information differently than sets of rules, making possible different computational procedures.

Analogies

Analogies play an important role in human thinking, in areas as diverse as problem solving, decision making, explanation, and linguistic communication. Computational models simulate how people retrieve and map source analogs in order to apply them to target situations. The explanation schema for analogies is:

Explanation target:
• Why do people have a particular kind of intelligent behavior?

Explanatory pattern:
• People have verbal and visual representations of situations that can be used as cases or analogs.
• People have processes of retrieval, mapping, and adaptation that operate on those analogs.
• The analogical processes, applied to the representations of analogs, produce the behavior.
The constraints of similarity, structure, and purpose overcome the difficult problem of how previous experiences can be found and used to help with new problems. Not all thinking is analogical, and using inappropriate analogies can hinder thinking, but analogies can be very effective in applications such as education and design.

Images

Visual and other kinds of images play an important role in human thinking. Pictorial representations capture visual and spatial information in a much more usable form than lengthy verbal descriptions. Computational procedures well suited to visual representations include inspecting, finding, zooming, rotating, and transforming. Such operations can be very useful for generating plans and explanations in domains to which pictorial representations apply. The explanatory schema for visual representation is:

Explanation target:
• Why do people have a particular kind of intelligent behavior?

Explanatory pattern:
• People have visual images of situations.
• People have processes such as scanning and rotation that operate on those images.
• The processes for constructing and manipulating images produce the intelligent behavior.

Imagery can aid learning, and some metaphorical aspects of language may have their roots in imagery. Psychological experiments suggest that visual procedures such as scanning and rotating employ imagery, and recent neurophysiological results confirm a close physical link between reasoning with mental imagery and perception.

Connectionism

Connectionist networks consisting of simple nodes and links are very useful for understanding psychological processes that involve parallel constraint satisfaction. Such processes include aspects of vision, decision making, explanation selection, and meaning making in language comprehension. Connectionist models can simulate learning by methods that include Hebbian learning and backpropagation. The explanatory schema for the connectionist approach is:

Explanation target:
• Why do people have a particular kind of intelligent behavior?

Explanatory pattern:
• People have representations that involve simple processing units linked to each other by excitatory and inhibitory connections.
• People have processes that spread activation between the units via their connections, as well as processes for modifying the connections.
• Applying spreading activation and learning to the units produces the behavior.

Simulations of various psychological experiments have shown the psychological relevance of the connectionist models, which are, however, only very rough approximations to actual neural networks.

Theoretical Neuroscience

Theoretical neuroscience is the attempt to develop mathematical and computational theories and models of the structures and processes of the brains of humans and other animals. It differs from connectionism in trying to be more biologically accurate by modeling the behavior of large numbers of realistic neurons organized into functionally significant brain areas. In recent years, computational models of the brain have become biologically richer, both with respect to employing more realistic neurons such as ones that spike and have chemical pathways, and with respect to simulating the interactions among different areas of the brain such as the hippocampus and the cortex. These models are not strictly an alternative to computational accounts in terms of logic, rules, concepts, analogies, images, and connections, but should mesh with them and show how mental functioning can be performed at the neural level. The explanatory schema for theoretical neuroscience is:

Explanation target:
• How does the brain carry out functions such as cognitive tasks?

Explanatory pattern:
• The brain has neurons organized by synaptic connections into populations and brain areas.
• The neural populations have spiking patterns that are transformed via sensory inputs and the spiking patterns of other neural populations.
• Interactions of neural populations carry out functions including cognitive tasks.

From the perspective of theoretical neuroscience, mental representations are patterns of neural activity, and inference is transformation of such patterns.