Cognitive Science: Emerging Perspectives and Approaches

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Introduction

The official beginning of cognitive science is usually placed as the Dartmouth symposium on information theory in 1956 (Miller, 1979). In Cognitive Psychology, George Miller published his seminal paper on short-term memory capacity 7±2 and Leon Festinger published his work on Cognitive Dissonance in 1956 (Bechtel, Abrahamsen, & Graham, 1998). Artificial Intelligence as a discipline was born in 1956. Advances in key interfacing disciplines especially computer science, psychology, neuroscience and linguistics enabled the development of Cognitive Science as a discipline of its own studying the mind. In the last 50 years, cognitive science and its interfacing disciplines have developed at a tremendous pace resulting in an a significant expansion of research on the brain, intelligent machines and the mind.

Cognitive science can be roughly defined as the study of the mind or mental processes. Cognitive science has also been defined as the study of the nature of intelligence. According to the Stanford Encyclopedia of Philosophy, Cognitive science "is the interdisciplinary study of mind and intelligence, embracing philosophy, psychology, artificial intelligence, neuroscience, linguistics, and anthropology". In contrast, Mandler (1986) has said that after 25 years that there is no single definition of Cognitive Science. Whatever the specific definition of cognitive science is, what has emerged is a strong interdisciplinary enterprise to understand the mind. Multiple definitions exist for mind and the sciences of the mind including Psychology and Cognitive Science has played a critical role in defining and understanding mind. This chapter discusses the major approaches to studying the mind including the information processing approach, cognitive modeling, cognitive neuroscience, embodied and situated cognition as well as the emerging trends of increasing interdisciplinarity and pluralism in cognitive science.

Information processing approach

The predominant approach in the study of mind is the computational theory of mind (Thagard, 1995). The computational or information processing view aims to understand the mind in terms of processes that operate on representations. The basic assumption is that any cognitive process can be thought as a computable function. The information processing approach argues that cognition is understood in terms of discrete, mental representations (symbols) and cognitive processes are transformation of such representations or symbols described in terms of rules or algorithms. Using the information processing, cognitive psychology has progressed well in the last 50 years resulting in detailed knowledge of processes including perception, attention, memory, language and decision-making. Traditional cognitive psychology uses behavioral experiments to understand the cognitive and emotional processes. As an example, beginning with psychophysics in the 19th century the study of visual perception has elucidated many of the mechanisms involved in different aspects of vision like color, shape and motion that has also led to the development of detailed computational models and links to neural mechanisms underlying vision (Palmer, 1999).

Levels of Processing

Most of cognitive psychology is at the level of representations and algorithms. A critical development is the three levels of description proposed by David Marr (Marr, 1982). According to Marr, the mind can be explained in terms of three different levels: computational, algorithmic, and implementational. The computational level focuses on the computations performed by a system. The algorithmic level focuses on the algorithms used to perform the computations given that many algorithms could be used for a given computation. The algorithms are usually implemented in a physical system and the implementational level focuses on the way algorithms are implemented. In the context of the mind, the implementational level focuses on the brain implements various algorithms or mental/cognitive processes. A closely related analysis of information processing approach is discussed by Palmer & Kimchi (1986). The three important concepts in the information processing approach are informational description, recursive decompositions and physical embodiment. A mental event can be described in terms of input information, the operation performed on that input, and output information. Any such event can be decomposed into events at a lower level and the way they are related. Information is carried by representations and mental/cognitive processes perform operations on to change the representations.

Representations and Structures

Representations can be of different types. A simple way to think of representations is in terms of digital or discrete and analog representations. Symbolic approaches to mind have opted for essentially discrete representations. Connectionist approaches typically favor analog representations. The type of representations used in the connectionist approach is usually subsymbolic i.e., representations that are not constituted by other representations. This can be contrasted with symbolic representations that are constituted by other representations. Thagard (2005) discusses different types of representations and the role they play in different cognitive processes.

In contrast to mental representations, Jackendoff (2007) has focused on mental structures. Mental structures differ from mental representations in terms of intentionality. While mental representations are intentional, mental structures are non-intentional and a person perceives a given a visual scene or spoken sentence due to the presence of mental structures in the mind. Mental structures are not "about" entities in the world. A sentence is a set of phonological, syntactical, and semantic structures each of which is hierarchically structured. According to this view, a pertinent question is to explore the level of mental structures and the interfaces among them.

Modularity

The concept of modularity of mind assumes that the mind is composed of separate (possibly innate) structures that have a specific function and has developed through evolutionary processes. According to Fodor (1983), modules have certain properties that include domain specificity, information encapsulation, obligatory firing, fast, shallow outputs and a fixed neural architecture. Mostly low-level processes are modular and high-level processes like memory are not modular. Pylyshyn (1999) has emphasized that the most important aspect of a module is encapsulation i.e., the processes inside a module are not subject to cognitive influences from outside the module. He argued that early visual perception is an example of such a module with the property of encapsulation. In the context of cognitive neuroscience, this leads to the notion of localization of function i.e., identification of a neural structure that performs a specific, possibly unique function. Cosmides & Tooby (1997) have argued for modules not specific to perceptual or motor aspects but for specific adaptive functions like social understanding and tool use based on evolutionary arguments and have proposed evolutionary psychology as a way to study such processes.

On a different note, Karmiloff-Smith (1994) has argued that modules or encapsulation of mental capacities occur through development and are not innate. It is experience and expertise that enables the formation of a module specialized for certain mental activities. A slightly different notion of modularity has been proposed by Jackendoff (2007). A mental structure makes sense only for the part of the mental module or brain area processing that structure. Information is broadcast only through the interfaces that are available between levels i.e., interface between one level of a structure with a level of another structure. Each structure has its own format and hence, is domain-specific. That is the structure can be used or understood only within a particular domain or module. If a particular aspect in one structure does not have a direct correlate in another structure, then these structures are to some extent informationally encapsulated

(Jackendoff, 2007).

Modeling and Simulation

Symbolic Modeling

The symbolic modeling approach aims to write a computer that can model or simulate cognitive processes and produce output that corresponds with human behavior. The use of computer programs or models to simulate cognitive processes has several advantages. They include precise statement of theories and development of predictions based on the theories. Miller, Gallanter & Pribram (1967) proposed Test-Operate-Test-Exit units as the basis for explaining cognitive processes. Herbert Simon and Alan Newell (Simon & Newell, 1972) used production systems to simulate cognitive processes.

Symbolic modeling can be performed through the development of a cognitive architecture based on theories of cognition (Anderson et al., 2004; Meyer & Kieras, 1997; Newell, 1990; Sun, 2003; Sun, 2009). Some of the cognitive architectures that have been designed and implemented for modeling various cognitive processes include ACT-R (Anderson et al., 2004), Soar (Newell, 1990), CLARION (Sun, 2003), CHREST (Gobet et al., 2001), and EPIC (Meyer & Kieras, 1997).

ACT-R (Anderson et al., 2004; Anderson et al., 2008) has two types of memory modules along with their own buffers. The declarative knowledge is represented in the form of chunks that can be accessed through buffers. The procedural memory module contains productions i.e., knowledge of how to perform actions. In ACT-R, only one production at a time can be executed that modifies information in the buffers. In addition, the ACT-R has a perceptual-motor module that interfaces with the world. All the modules in ACT-R can only be accessed through their buffers. Soar (Newell, 1990) employs searching through a problem space that brings the system gradually closer to and eventually reach a goal state. Soar is based on a production system and employs chunking. In Soar, each move consists of an elaboration phase and a decision procedure.

CLARION (Sun, 2003; Sun, 2009) consists of an action-centered subsystem to control actions, the non-action-centered subsystem to store knowledge, the motivational subsystem, and the meta-cognitive subsystem to monitor and control other subsystems. It uses two types of representations (discrete as well as analog) in each system. CHREST (Gobet et al., 2001) combines mechanisms involved in short-term memory with the strategies that are dependent on long-term memory. The chunks held in long-term memory are referenced by information in short-term memory and these chunks are identified through a discrimination network based on information from the perceptual system (Gobet et al., 2001). EPIC (Meyer & Kieras, 1997) consists of multiple processors that operate in parallel and employs production rules for accomplishing a given task. EPIC generates various events that matches with human performance and it has been used successfully to model multitask performance.

Connectionism

Connectionist models have been inspired by the neural architecture of the brain although the neurons they employ are a much simplified version of the real neurons. They typically employ parallel distributed processing and degrade in a graded manner. Processing is spread over multiple units and any loss results only in partial information loss and not in a all-or-none manner that is typical of computer memories. Smolensky (2000) have pointed out that connectionism entails commitment to mental representations are distributed patterns of neural activity and mental processes involves parallel transformations of neural activity patterns and changes in connections. In a connectionist model, knowledge is acquired through the interaction of the learning rule, architecture and modification through experience. The models developed by the connectionists do not rely on explicit rules but learn through examples and are said to utilize sub-symbolic representations (Rumelhart & McClelland, 1986).

Connectionist models are networks made up of neurons or neuron-like elements and the connections between these neurons are typically modified through experience (Rumelhart & McClelland, 1986). The neural networks employ feed forward or recurrent connections. Many learning algorithms are used for changing weights in a neural network with the most popular ones being Hebb's rule and back propagation algorithm. Learning algorithms can be supervised, unsupervised, or based on reinforcement. Recurrent connections have been incorporated in an essentially multi layer neural network architecture to handle time in a more explicit manner to model language processing (Elman, 1990). Elman (2004) has argued that recurrent neural networks can "learn" distinctions such as *subject* and *object*, and generalisations of words at positions not experienced by the network. Grossberg and colleagues have developed detailed models of perception and cognition based on their adaptive resonance theory (Carpenter & Grossberg, 2003).

Dynamical Approach

Recently approaches based on nonlinear dynamics that focuses on changes in various parameters over time have been proposed as an alternative to symbolic approaches to cognition. Nonlinear dynamics involves modeling or analyzing the system using a set of non-linear differential equations. Dynamical systems theory provides a set of techniques including stability analysis to study cognitive dynamics. Arguments have been made for the extensive use of dynamic approaches (Gibbs, 2006; Kelso, 1995; van Gelder, 1998). For example, Skarda & Freeeman (1987) used nonlinear dynamics to explain perception. Kelso (1995) developed a nonlinear dynamical model for finger wagging which explained and predicted behavioural results from finger wagging experiments. van Leeuwen (2007) has used nonlinear dynamics based analyses to explain perceptual awareness.

Debate between Symbolic, Connectionist and Dynamic Approaches

Fodor & Pylyshyn (1988) argue that the connectionist models are inadequate as a representational system focusing on the properties of productivity, systematicity, and coherence. They argue that classical cognitive theories can handle productivity of thought through a functional distinction between memory and program. Connectionist models due to their lack of distinction between memory and computational structure cannot support *productive cognitive capacities*. They also argue that since connectionist representations are not structured, they cannot adequately handle systematicity. Based on the arguments above, Fodor & Pylyshyn (1988) conclude that connectionism does not provide an alternative new approach to cognition and can at best be thought of as an implementation of symbolic processing. The connectionist modelers have responded in multiple ways to address the criticisms of those arguing for symbolic approaches (Bechtel & Abrahamsen, 2002). These include efforts to explicitly implementing rules and representations, implementing functionally compositional representations, and building networks that acquire procedural knowledge without explicitly forming structural representations (Bechtel & Abrahamsen, 2002). Efforts have also been made to combine symbolic and connectionist approaches and develop a hybrid approach (Sun, 2009).

Van Gelder (1998) has argued for a dynamical approach to cognitive science and that the computational approach to cognitive science using representations is not the appropriate method to study the mind. The dynamical approaches so far has been mostly limited themselves to phenomena in perception and action. Dietrich and Markman (2003) have argued that discrete representations are necessary for cognition. The dynamic approach to mind is not necessarily against the notion of representations. An attractor in state space or measures based on non-linear dynamical analysis might play the role of a representation. It should be noted that the connectionist models are also dynamic in nature and can be considered as constituting a dynamic approach to studying cognition. Dale & Spivey (2005) have argued for the use of symbolic dynamics framework that combines discrete representations and continuous dynamics. In symbolic dynamics, a system with dynamics is discretized to form discrete symbols, which constitutes a state of the system. The symbolic dynamics provides a way to focus on system dynamics and discrete aspects of representations.

The Promise of Cognitive Neuroscience

Cognitive neuroscience has employed multiple techniques to study cognition including single cell electrophysiology, lesion studies, brain stimulation, electroencephalography (EEG) and event related potentials (ERP), magnetic encephalography (MEG), neuroimaging using positron emission tomography (PET) and functional magnetic resonance imaging (fMRI), and transcranial magnetic stimulation (Gazzaniga, Ivry, & Mangun, 2002). Lesion studies and studies with patients have been used to identify the neural structures underlying specific cognitive mechanisms (Gazzaniga, Ivry, & Mangun, 2002**;** Kolb & Wilshaw, 1996).

Single cell electrophysiology has enabled us understand the computational mechanisms underlying cognition by linking behavior with electrophysiological responses. Prominent among such electrophysiological studies is the Nobel Prize winning work by Hubel and Wiesel on the visual cortex primarily with monkeys (Hubel & Wiesel, 2004). Desimone and colleagues have shown that attention modulates the activity of single cells in V4 or inferotemporal cortex (Moran & Desimone, 1985).

The EEG methodology (Handy, 2005; Luck, 2005) consists of noninvasive recordings of brain electrical activity that includes the measurement of event-related potential (ERP) waveforms evoked in response to external stimuli. The ERP waveforms are computed by averaging time-locked EEG signals and different components are identified in the ERP waveforms that may correspond to specific cognitive processes. Spectral analysis of EEG provides information about different rhythms that play a critical role in cognition (Buzs·ki, 2006). The analysis of EEG signals also can provide a measure of synchronized activity of different brain regions under different conditions. Spatial localization of cognitive processes has been aided by the development of neuroimaging techniques. The fMRI methodology measures the hemodynamic response associated with neural activity in the brain (Gazzaniga, Ivry, & Mangun, 2002). Using fMRI, many brain areas that play a critical role in specific cognitive processes have been identified.

We shall illustrate the developments in cognitive neuroscience with some examples: attention, neuroeconomics and social cognition. Different aspects or networks of attention have been identified and tasks like attentional network test (ANT) have been used to identify attention networks (Posner & Rothbart, 2007a). Using ANT, Posner and his colleagues have identified three attentional networks: alerting, orienting and executive attention. The alerting network involves areas including locus coerculus, right frontal, and the parietal cortex and this network is modulated by norepinephrine. The orienting network involves areas including superior parietal cortex, temporal parietal junction, frontal eye fields, and superior colliculus and this network is modulated by acetylcholine. The executive attention network involves areas including anterior cingulated, lateral ventral cortex, prefrontal cortex, and basal ganglia and this network is modulated by dopamine.

It should be noted that any cognitive task and involves the activation of large neural networks involving multiple areas in the brain. However, the component mental or cognitive processes could be localized in the brain. For example, while many areas may play a role in orienting to a spatial location or object, different areas may play a different role. For example, the temporal parietal junction might play the role of an interrupt and the superior colliculus might play a critical role in the movement of the focus in orienting (Posner & Rothbart, 2007a).

A developing multidisciplinary area is neuroeconomics in which cognitive neuroscience techniques have been applied to the experimental tasks involving economic decisions to explain economic theories of human behavior (Camerer, Loewenstein, & Prelec, 2005). The field of neuroeconomics provides another example of interdisciplinary research with (i) the neuroscientists and psychologists helping the economists to better understand the process of human decision making and (ii) testing the economic theories with the help of cognitive neuroscience.

Another area of research that has become prominent in recent years is the study of cognitive and neural processes underlying meditation (Raffone & Srinivasan, 2009). Cognitive processes have been shown to be affected by the practice of meditation (Srinivasan & Baijal, 2007). Changes in brain activity as indexed by changes in EEG have been shown with concentrative meditation, especially theta activity in frontal and parietal regions (Baijal & Srinivasan, in press). Recently an adaptive workspace based model has been proposed to explain the changes in neural activity due to meditation, which will provide further impetus to meditation research (Raffone & Srinivasan, 2009).

Some criticisms of neuroimaging have emerged in the past few years (Uttal, 2001) suggesting that neuroimaging research is similar to the phrenology research in the 19^{th} century and it would be difficult to localize functions to specific brain areas. The brain activity underlying cognitive processes are distributed across many brain areas making it difficult to localize functions to specific brain areas. Also same brain area may underlie multiple functions. Bechtel & Richardson (in press) have argued that the main purpose of neuroimaging is to provide a way to functionally decompose cognitive processes rather than just localization of functions. In addition to neuroimaging, a strong effort is being made to link specific hypotheses about brain structure and function and explicitly link it to computational models that employs realistic neural modeling (O'Reilly & Munakata, 2000) leading to the emergence of computational cognitive neuroscience.

Genetics, Neuroscience and Cognition

The other significant development is the use of genetic techniques in understanding mental and neural processes (Chaudhuri, 2008). Molecular mapping provides many advantages over traditional neuroimaging approaches including rapid induction, better spatial resolution, combination with other histological approaches, and potential for large-scale analysis. Some disadvantages include poor temporal resolution, difficulties with quantitative analysis, neuronal expression specificity, and false positives (Chaudhuri, 2008). Molecular mapping techniques have been used to study perception of complex visual stimuli (Broad et al. 2000; Montero, 2000; Zangenehpour and Chaudhuri, 2005). For example, Broad et al. (2000) found enhanced activation with upright faces (not inverted faces) in inferotemporal cortex, amygdala and hippocampus by examining *c-fos* (an immediate early gene) mRNA expression in those areas. Montero (2000) has shown enhancement in *c-fos* induction due to attentional factors in the visual and somatosensory cortices of rats after they have explored a novel environment. Avi Chaudhuri and colleagues have extensively used molecular mapping for studying the visual system (Zangenehpour and Chaudhuri, 2005; Chaudhuri, 2008).

In a series of studies exploring the link between genes, networks and experience, Posner and colleagues have investigated attentional networks in children and adults (Posner & Rothbart, 2007b). An example is the executive attention network, which involves areas like the anterior cingulate cortex and the network is modulated by dopamine (Posner & Rothbart, 2007a). To study the interaction between genes and parenting, Sheese, Voelker, Rothbart & Posner (2007) studied eighteen month old children and their caregivers using a free play task. They found that parenting greatly affected key symptoms of ADHD like activity level, impulsivity and risk taking only the children with one form of the Dopamine 4 receptor gene (DRD4), the 7 repeat allele, that has been implicated in attention and sensation seeking (Sheese et al., 2007). Parenting did not have much of an effect on children without the 7 repeat allele, DRD4 gene. Posner has argued that the 7 repeat DRD4 gene might be under positive selection since it enables the child to be significantly influenced by parenting and in general, the dominant culture (Posner, 2007). The view emanating out of these studies show the importance of parenting and that the ability of children to handle complex situations depend on gene-environment interactions.

Back to the Body: Embodied Cognition

The embodied cognition approach focuses on the critical role played by the body in mind (Anderson, 2003). The embodied cognition approach is typically framed against the traditional cognitivist approach and computational psychology. According to this view, the traditional cognitivist view focuses on disembodied approach and neglects the role of body in mind. The experience of “bodies in action” is important for understanding the mind. The embodied cognition approach claims that the body continuously affects and influences the mind in a substantial manner that cannot be reduced to neural activity. In the embodied approach, not only our body plays a special role in cognition at multiple levels, but also other bodies constitute a special object for perception.

Gallagher (2005) has extensively addressed the role of body in shaping the mind and argues that perception is grounded by the body. More specifically, Gallagher addresses “to what extent, and in what ways, are consciousness and cognitive (noetic or mental) processes, which include experiences related to perception, memory, imagination, belief, judgment, and so forth, shaped or structured *prenoetically* by the fact that they are embodied?” (page 2 in Gallagher, 2005). He proposes a distinction between body schema and body image. Body schema is an unconscious system of sensori-motor capacities that controls body movement and plays a critical role in many cognitive functions. The embodiment approach argues that new methods based on dynamical systems theory is needed since the body affects the mind continuously and the traditional representational approach is insufficient. The typical decomposition of cognitive processes is not the right methodology to study embodied cognition.

In case of perception, the embodied approach emphasizes the role of action emphasizing perception-action loops or sensorimotor contingencies (Noe, 2004). In the context of language processing, embodiment approaches focus on the critical dependence of language processes on perceptual/motor processes (Barsalou, 1999). Related is the idea of conceptual blending (Fauconnier & Turner, 2006). Social cognition in the context of embodiment is conceived similar to a sensorimotor activity. In emotion research, support for embodiment comes from findings indicating that perceived emotion of others’ is affected by the bodily expression of emotion of a person (Niedenhal, 2007). One strand of research using the embodied approach in social cognition focuses on simulation theory (Gordon, 1996). We know about other minds or other bodies by simulating those processes based on knowledge about our body and cognition.

While agreeing that the concept of embodiment and the critical role of body is important for cognitive science, it is not clear whether all the mental processes are embodied. Goldman and Vignemont (2009) have questioned whether social cognition is embodied. They propose four general constraints on the definition of embodied cognition, discuss four definitions of embodiment, and evaluate whether they satisfy the constraints they have proposed. They argue that body format representations could play a role in social cognition but embodied cognition cannot account for all social cognitive processes like personality judgments and social beliefs. Clark (1999) has argued for embodied cognitive science but has also wondered whether embodiment can handle "representation-hungry" problems like abstract reasoning.

Back to the Environment: Situated cognition

Closely linked to the embodied cognition approach is the situated cognition approach. The situated cognition approach focuses on the environment and argues that the environment is a key aspect/determiner of mind. In fact proponents of the situated cognition approach argue that the mind is not just dependent on the brain or the body but arises out of interactions with the environment. The environment is constituted by social, cultural and physical factors and these aspects determine the way mind works. Situated cognition work strongly draws on the perception research and views of James Gibson (Gibson, 1977). Gibson introduced the idea of affordances that indicates the way environment and organism interact and fit with each other. Gibson also emphasized bodily action in his ecological approach to perception. He argued for a direct perception view and argued against the use of representations. In robotics, Brooks (1991) has emphasized the importance of situated cognition in building machines that effectively interacts with the environment without using representations. To summarize situated cognition views emphasize interactions between the person and the environment, are generally against representations and prefer a dynamic approach. The situated cognition approach has been applied to many phenomena including perception, memory, and social cognition (Barnier, Sutton, Harris, & Wilson, 2008; Smith & Semin, 2007).

An example of the situated cognition is the work by Edward Hutchins on distributed cognition (Hutchins, 1995). The work focuses on the interaction between an agent and the environment especially the human artifacts. These artifacts not only help us perform certain tasks but change the way we think by reducing cognitive load and providing alternate forms of memory. The distributed cognition approach views the human-environment system as consisting of a set of representations that are neither in the human nor in the environment but distributed between the two. The way representations are transformed so that adaptive behavior takes place constitutes the phenomena studied under the distributed cognition approach. In the distributed cognition approach, the boundary of cognition is not inside a person but includes other persons and environment. In addition, the mechanisms of cognition include human artifacts as well and the external environment becomes a part of the cognitive system (Hutchins, 1995). We use and manipulate the external environment to reduce cognitive load

The situated cognition approach has not gone unchallenged (Vera & Simon, 1993; Anderson, Reder, & Simon, 1996). The situated cognition approach commonly uses representations (which are usually symbolic) and the approach does not scale up to complex tasks without utilizing the concept of representations (Vera & Simon, 1993). Anderson, Reder, & Simon (1996) have focused on claims from situated cognition in the context of learning and have argued strongly for a cognitive approach based on symbolic representations. Bechtel (in press) has argued that the mind/brain is the appropriate locus of control for an agent situated in an environment.

The situated cognition approach can be linked to efforts to study cognitive processes as dependent on the culture in which humans are located. Bruner (1990) has argued for the central role of meaning in the study of cognition and has criticized the computational metaphor of mind. According to Bruner (1990), the study of mind is possible only by understanding meaning-making which is possible only in the context of human experience. Intentional states are realized through participation in a culture. Cultural approaches focus both on the role of mind in the development of cultural practices as well as the role of culture in shaping the mind. The studies on culture and cognition question the universality of cognitive processes and emphasize differences in mental/cognitive processes as a function of different cultures. A prominent example is the work of Richard Nisbett (Nisbett, 2003).

Pluralist Cognitive Science

The different approaches of cognitive science diverge in terms of the way they handle the issue of representations. They also differ in terms of the phenomena that are studied with the different notions of representations. The majority of cognitive scientists agree that the notions of computation and representation are important for cognitive science and routinely employ these concepts for explaining different processes. While the approaches of situated cognition and embodied cognition are against the classic notion of cognitivism and hence the concept of symbolic representations, it is not clear that they actually are against or inconsistent with the concept of representations in general. Given that representations are part of the explanatory framework of cognitive science, how do we reconcile the differing concepts or types of representations? A recent special issue in the Journal of Experimental and Applied Artificial Intelligence has been dedicated for pluralism in cognitive science and a case is made for a pluralist approach to cognitive science (Dale, 2008).

Another type of pluralism to consider would be in terms of the different levels of understanding the mind. While these levels may not be as independent as Marr (1982) had envisaged, the notion of levels and focusing on different levels and relating different levels would be a fruitful endeavor and lead to further progress in cognitive science. Related to this pluralism is the combination of different methodologies to study the mind. For example, computational modeling can be combined with cognitive neuroscience to link specific symbolic architectures (Anderson, Fincham, Qin, & Stocco, 2008) or connectionist architectures (O'Reilly & Munakata, 2000) to develop computational cognitive neuroscience. Similarly, situated cognition approaches can be combined with cognitive neuroscience to understand the neural processes that take place when a person performs an action in a given environment. As technologies develop, such combination of methodologies would become viable ways of understanding the mind. The representational view of mind can fruitfully combine with the embodied and situated cognition approaches to understand the mind as embodied as well as situated in the world (Thagard, 2005).

Conclusions

The chapter has mainly focused on the basic concepts and approaches used in cognitive science. It should not be forgotten that cognitive science has a tremendous role to play in terms of applications in different areas including education, development of intelligent systems, and mental health. As research on basic problems progress, new applications will emerge. One can expect significant applications in psychopathology (both diagnosis and treatment), education (better techniques for learning based on knowledge about the mind and brain) and human-machine interfaces.

In the Indian context, there has been a recent surge in the education and research in Cognitive Science in India (Srinivasan, Gupta, & Pandey, 2008). Recent research initiatives in Cognitive Science supported by the Government of India has gone a long way in popularizing Cognitive Science research and is expected to reinvigorate research on the mind sciences in India.

At present, we have different positions and methodologies vying with each other to explain the mind. It is not clear how cognitive science will emerge and develop in the near future. One can definitely expect a lot of work on modeling and simulations leading us towards the production of artificial minds as well increase in the studies aimed at understanding the neural mechanisms of cognition through further development of cognitive neuroscience. Richard Thompson (Page 48 in R. Solso, 2000) has stated that "Perhaps the most important advances regarding the 'mind' in the 21st century and beyond will come from (1) the development of 'artificial ' minds that are equal or superior to the human mind in all its aspects, and (2) the increasing characterization of brain substrates of verbal and other aspects of behavior. As these developments occur, the mysteries of the mind and consciousness will gradually fade from our collective awareness." Bechtel, Abrahamsen, & Graham (1998) have pointed out the existence of "simultaneous pulls downwards into the brain and outwards into the world". Integration of these multiple approaches will determine the success of the interdisciplinary cognitive science.

How cognitive science will turn out is unpredictable for many reasons. Margaret Boden, in her last chapter of the monumental "Mind as Machine" history lists as much as 27 research areas as promising and picks the work on integrated mental architectures that include emotion and motivation as the most promising. Many significant problems remain unsolved including conscious experience, self, intentionality, the relation between life and mind. She also points out that the solution to major problems in Cognitive Science will depend on fundamental and reciprocal advances in philosophy, psychology, anthropology, neuroscience and AT/A-Life. Amen!

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