Distributed Cognition

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Like all other branches of cognitive science, distributed cognition seeks to understand the organization of cognitive systems. Like most of cognitive science, it takes cognitive processes to be those that are involved in memory, decision making, inference, reasoning, learning, and so on. Also following mainstream cognitive science, it characterizes cognitive processes in terms of the propagation and transformation of representations. What distinguishes distributed cognition from other approaches is the commitment to two related theoretical principles. The first concerns the boundaries of the unit of analysis for cognition. The second concerns the range of mechanisms that may be assumed to participate in cognitive processes. While mainstream cognitive science looks for cognitive events in the manipulation of symbols (Newell, et.al, 1989), or more recently, patterns of activation across arrays of processing units (Rumelhart, et.al, 1986; McClelland, et.al., 1986) inside individual actors, distributed cognition looks for a broader class of cognitive events and does not expect all such events to be encompassed by the skin or skull of an individual.

When one applies these principles to the observation of human activity "in the wild", at least three interesting kinds of distribution of cognitive process become apparent: cognitive processes may be distributed across the members of a social group, cognitive processes may be distributed in the sense that the operation of the cognitive system involves coordination between internal and external (material or environmental) structure, and processes may be distributed through time in such a way that the products of earlier events can transform the nature of later events. The effects of these kinds of distribution of process are extremely important to an understanding of human cognition.

The roots of distributed cognition are deep, but the field came into being under its current name in the mid-1980s. In 1978, Vygotsky's *Mind in Society* was published in English. Minsky published his *Society of Mind* in 1985. At the same time, Parallel Distributed Processing was making a comeback as a model of cognition (Rumelhart, et al, 1986). The nearly perfect mirror symmetry of the titles of Vygotsky's and Minsky's books suggests that something special might be happening in systems of distributed processing, whether the processors are neurons, connectionist nodes, areas of a brain, whole persons, groups of persons, or groups of groups of persons.

Mind in Society

For many people, distributed cognition means cognitive processes that are distributed across the members of a social group (Salomon, 1993). The fundamental question here is how the cognitive processes we normally associate with an individual mind can be implemented in a group of individuals? A wide range of disciplines in the social sciences has explored this question.

Treating memory as a socially distributed cognitive function has a long history in sociology and anthropology. Durkheim, and his students, especially Halbwachs (1925), maintained that memory could not even be coherently discussed as a property of an isolated individual. Roberts (1964) proposed that social organization could be read as a sort of architecture of cognition at the community level. He characterized the cognitive properties of a society (its memory capacity and ability to manage and retrieve information) by looking at what information there is, where it is located, and how it can move in a society. Schwartz (1978) proposed a distributional model of culture that emphasized the distribution of beliefs across the members of a society. Romney, Weller, and Batchelder (1986) created quantitative models of the patterns of cultural consensus. The identification of patterns raised the question of why such patterns form. Sperber (1985) introduced the idea of an epidemiology of representations. He suggested an analogy in which anthropology is to psychology as epidemiology is to pathology. In the same way that epidemiology addresses the distribution of pathogens in a population, anthropology should treat questions about the distribution of representations in a community. A similar set of developments followed from Dawkins' (1976) discussion of 'memes' as the cultural analog of genes. These ideas have now coalesced in the field of memetics (Blackmore, 1999).

March and Simon (1958) argued that organizations can be understood as adaptive cognitive systems. Juries are an important class of distributed problem solving organization and they have been intensely studied by social psychologists (Hastie, 1993). Of course, in social psychology there is a vast literature on small-group decision making, some of which discusses the properties of aggregates .

Scientific communities have received special attention because the work of science is fundamentally cognitive and distributed. The phenomena that have been explored include how the organization of communication media in a scientific community affect the kinds of things the community can learn (Thagard, 1993), how conditions external to the individual scientists can affect their individual choices in ways that lead to different high-level structures to emerge (Kitcher, 1990), how the distribution of cognitive activity within social networks and between people and inscriptions accounts for much of the work of science (Latour 1987), and how scientific facts are created by communities in a process that simply could not be fit into the mind of an individual (Fleck, 1935).

Economists have been interested in the tension between what is individually rational and what is rational at the aggregate level. This theme has been explored in game theory under the rubric of the Prisoner's Dilemma, the paradox of the commons, and other cases where individual rationality and group rationality diverge (Rappaport, 1966).

Anthropologists and sociologists studying knowledge and memory, social psychologists studying small-group problem solving and jury decision making, organizational scientists studying organizational learning, philosophers of science studying discovery processes, and economists and political scientists exploring the relations of individual and group rationality, all have taken stances that lead them to a consideration of the cognitive properties of societies of individuals. There is ample evidence that the cognitive properties of a group can differ from the cognitive properties of the members of the group. It is important to keep this fact in mind when thinking about human cognitive capabilities.

The Society of Mind

The work described above looks for mind-like properties in social groups. This is the *Mind in Society* reading. The metaphor can be run the other way as well as is done in Minsky's *Society of Mind* (1985). Rather than using the language of mind to describe what is happening in a social group, the language of social groups can be used to describe what is happening in a mind.

Minsky argued that to explain intelligence we need to consider a large system of experts or agencies that can be assembled together in various configurations to get things done. Minsky also allowed that a higher level agency itself could be composed of lower level agencies. With Papert (Minsky and Papert, 1988), he argued that the low-level agencies (the ones that take on "toy-sized problems") could be implemented as distributed computations in connectionist nets**.** Minsky said, "...each brain contains hundreds of different types of machines, interconnected in specific ways which predestine that brain to become a large, diverse society of partially specialized agencies." (1988) What this means, of course is that the cognition of an individual is distributed cognition too.

A problem that remained unsolved by Minsky's work was "how such systems could develop managers for deciding, in different circumstances, which of those diverse procedures to use" (1988). That is, how can the relations among the agencies get organized to perform new functional skills? To solve this problem, Minsky & Papert invoked biological maturation. An alternative way to approach this problem is to note that each "society of mind" resides and develops in a community of similar societies of mind. This means, of course, that both what's in the mind, and what the mind is in are societies. Getting internal agencies into coordination with external structure can provide the organization of the relations between the internal agencies that is required to perform the new functional skill.

Vygotsky developed this idea of the social origins of individual psychological functions in S*ociety of Mind* (Vygotsky, 1978; Wertsch, 1985). He argued that every high-level cognitive function appears twice: first as an interpsychological process and only later as an intrapsychological process. The new functional system inside the child is brought into existence in the interaction of the child with others (typically adults) and with artifacts. As a consequence of the experience of interactions with others, the child eventually may become able to create the functional system in the absence of the others. This could be seen in Minsky's terms as a mechanism for the propagation of a functional skill from one society of mind to another. From the perspective of distributed cognition, this sort of individual learning is seen as the propagation of a particular sort of pattern through a community. Cultural practices assemble agencies into working assemblages and put the assemblages to work. Some of these assemblages may be entirely contained in an individual, and some may span several individuals and material artifacts. The patterns of activity that are repeatedly created in cultural practices may lead to the consolidation of functional assemblages, the atrophy of agencies that are rarely used, and the hypertrophy of agencies that are frequently employed. The result can be individual learning or organizational learning, or both.

Interaction as a source of novel structure

An important property of aggregate systems is that they may give rise to forms of organization that cannot develop in the component parts. Freyd (1983) argued that some of the features of language that are identified as linguistic universals could arise out of the necessity of sharing the linguistic code. For instance, the reason that linguistic categories tend to approximate discrete structures may have little to do with the organization of the brain, and everything to do with the problem of pushing a complex representation through a very narrow channel. As Minsky and Papert point out, symbols can be expected to arise where there are bottlenecks in communication. That means we should look for the origins of symbols at places where the information “traffic” is relatively low - or at the boundaries of our various units of analysis.

The phenomena related to the social distribution of cognition are most often investigated using ethnographic methods. In some cases, however, simulation models can be used to test hypotheses about the behavior of such distributed systems. For example, Hutchins and Hazlehurst (1995) explored Freyd’s ideas in a series of simulation models in which individuals (modeled by connectionist networks) interact with one another. They developed a robust procedure in which a shared lexicon emerges from the interactions of individuals. Hazlehurst and Hutchins (1998) demonstrated the emergence of reduced conventional sequences of lexical items - which they take to be the beginnings of syntax. These conventional sequences arise only in the condition of negotiated learning where the representing structures must simultaneously come to accurately represent the world and be shared among individuals, that is, be able to pass the communication bottleneck between individuals. Representations that are learned inside an individual, without the requirement of sharing them with others, come to represent the world, but do not show the reduced conventional code aspects that are the hallmarks of language and syntax.

By simultaneously considering the society of mind and mind in society, the distributed cognition approach provides a new place to look for the origins of complexity. Phenomena that are not predictable from the organization of any individual taken in isolation may arise in the interactions among individuals. Once having developed in this larger system, they may become elements of cultural practices and thereby become available for appropriation by individuals. This sort of scheme may be a partial solution to the paradox of how simple systems can lead to more complex ones.

The Material Environment.

A second major thread in the fabric of distributed cognition concerns the role of the material environment in cognitive activity. Again, the question of where to bound the unit of analysis arises. The potential of the material environment to support memory is very widely recognized. But, the environment can be more than a memory. Cognitive activity is sometimes situated in the material world in such a way that the environment is a computational medium.

Cognitive Artifacts are the *Things that Make Us Smart* in the title of Don Norman's (1993) book. The notion that cognitive artifacts amplify the cognition of the artifact user is fairly commonplace. If one focuses on the products of cognitive activity, cognitive artifacts do seem to amplify human abilities. A calculator seems to amplify one's ability to do arithmetic, writing down something one wants to remember seems to amplify one's memory. Cole and Griffin (1980) point out that this is not quite correct. When I remember something by writing it down and reading it later, my memory has not been amplified. Rather, I am using a different set of functional skills to do the memory task. Cognitive artifacts are involved in a process of organizing functional skills into cognitive functional systems.

Consider an example from the world of ship navigation (Hutchins, 1995). Navigators frequently face the problem of computing the ship's speed from distance traveled over a given period of time. If a ship travels 1500 yards in 3 minutes, what is the speed of the ship in knots? There are many ways to solve this problem. Most readers of this article would probably attempt to use a paper and pencil plus their knowledge of algebra to solve it. That procedure is effective, but not nearly as efficient as the "so-called" 3-minute rule. An experienced navigator need only see the problem stated to see that the answer is 15 knots. The speed in knots equals the number of hundreds of yards covered in 3 minutes. The use of this rule is a case of situated seeing. The rule itself is an internal cognitive artifact. But suppose the ship covered 4000 yards in 7 minutes? For that problem a material artifact called the 3-scale nomogram is more appropriate. A nomogram has three logarithmic scales; one each for distance, time, and speed. If the values of any two variables in a distance/rate/time problem are known, the other can be determined by laying a straightedge on the nomogram so that it touches the known values. The straightedge will touch the third scale at the value of the answer. It is clear that cognitive work is being done, but it is also clear that the processes inside the person are not, by themselves, sufficient to accomplish the computation. A larger unit of analysis must be considered. The skills of scale reading and interpolation are coordinated with the manipulation of objects to establish a particular state of coordination between the straightedge and the nomogram. This is a very different set of agencies than was involved in doing the problem via algebra and paper and pencil. In fact, the skills that are needed to use the nomogram are the things that Rumelhart, et.al., (1986) say humans are good at: pattern matching, manipulation of objects in the world, and mental simulation of simple dynamics.

A computation was performed via the manipulation of a straightedge and nomogram. And the nomogram was designed in such a way that the errors that were possible in algebra are impossible when using the nomogram. It is essential to distinguish the cognitive properties required to manipulate the artifact from the computation that is achieved via the manipulation of the artifact. This is a key point, and the failure to see it clearly has been the source of many difficulties in cognitive science.

Distributing cognition in time

Simon (1981) offered a parable as a way of emphasizing the importance of the environment for cognition. He argued that, as we watch the complicated movements of an ant on a beach, we may be tempted to attribute to the ant some complicated program for constructing the path taken. In fact, Simon says, that trajectory tells us more about the beach than about the ant. Similarly, in watching people thinking in the wild, we may be learning as much about their environment for thinking as about what is inside them. The environments of human thinking are not "natural" environments. They are artificial through and through. They develop over time. The crystallization of partial solutions to frequently encountered problems in artifacts such as the 3-minute rule and the nomogram is a ubiquitous strategy for the stabilization of knowledge and practice. Humans create their cognitive powers in part by creating the environments in which they exercise those powers.

Conclusion

It does not seem possible to account for the cognitive accomplishments of our species by reference to what is inside our heads alone. One must also consider the cognitive roles of the social and material world. But, how shall we understand the relationships of the social and the material to cognitive processes that take place inside individual human actors? This is the problem that distributed cognition attempts to solve.

According to Howard Gardner (1985) a more or less explicit decision was made in cognitive science to leave culture, context, history and emotion out of the early work. These were recognized as important phenomena, but their inclusion made the problem of understanding cognition very complex. The "Classical" vision of cognition that emerged was built from the inside out starting with the idea that the mind was a central logic engine. From that starting point, it followed that memory could be seen as retrieval from a stored symbolic database, that problem solving was a form of logical inference, that the environment is a problem domain, and that the body was an input device (Clark, 1996). Attempts to reintegrate culture, context, and history into this model of cognition have proved very frustrating. The distributed cognition perspective aspires to rebuild cognitive science from the outside in, beginning with the social and material setting of cognitive activity, so that culture, context, and history can be linked with the core concepts of cognition.

Developed by Edwin Hutchins, distributed cognition is the theory that knowledge lies not only within the individual but in the individual's social and physical environment. The dependence of the theory on the social and physical environment of the individual makes it very useful in analysing human-computer interactions and educational technologies. See also: external cognition, distributed intelligence and collective intelligence. Distributed cognition provides a radical reorientation of how to think about designing and supporting human-computer interaction. As a theory it is specifically tailored to understand-ing interactions among people and technologies. In this article we propose distributed cognition as a new foundation for human-computer interaction, sketch an integrated research framework, and use selections from our earlier work to suggest how this framework can provide new opportunities in the design of digital work materials. Socially distributed cognition describes group activity in the way that individual cognition has traditionally been describedâ€"computation realized through the creation, transformation, and propagation of representational states (Hutchins, 1995a; Simon, 1981). Central to this is the idea of work being distributed over a range of media and over a number of people.