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Distributed Cognition

Everyone agrees that cognition is distributed across parts of the brain; proponents of distributed cognition argue that the distribution of cognition extends to material settings and artifacts, to social interaction, and across time. A cognitive process involves representational states—in the world and in the head—that are brought into coordination with one another. This coordination may be purely internal, but it more typically involves interaction with one or more technologies, interactions among multiple persons, and/or incorporation of products of past cognitive activity.

Because cognitive processes may extend beyond the head of the individual, researchers of distributed cognition use a broader unit of analysis when studying cognitive systems. Depending on the goals of the analysis, the boundary of the cognitive system may be defined around a person working with a tool or artifact, a team of people and their tools, or the skull of a single individual. To avoid over-attribution of internal states, distributed cognition researchers prefer to work outside-in, using analysis of visible activity to set constraints on what must be happening in the internal cognitive system.

Hutchins's View of Distributed Cognition

Distributed cognition is most closely associated with the work of the cognitive anthropologist Edwin Hutchins (1948-) at the University of California, San Diego, and with his students and colleagues. In his groundbreaking research, Hutchins studied the work of a navigation team on a navy ship. The team used specialized tools and coordinated activity to accomplish more than could be done by any individual thinker. This led Hutchins to broaden his definition of what constituted the cognitive system and to argue that cognition is distributed in three fundamental ways: across the individual and aspects of the material environment; across multiple individuals interacting and communicating in an organized way; and across time, in that products of earlier cognitive processes change the nature of later cognitive tasks.

Material Distribution of Cognition

A cognitive task as mundane as multiplying two-digit numbers is rarely done in the head; instead, multiplication commonly involves a written representation of the problem or the use of a calculating device. Many familiar cognitive activities are impossible without such artifacts: clocks, for example, are manufactured precisely to support time-telling, and much instruction in the early grades is devoted to learning to read clock times. In complex domains like ship navigation, specialized tools and procedures have been developed over centuries to solve important, frequently recurring problems like determining the ship's location or speed. Mastering their use is essential to becoming an expert navigator.

While such artifacts seem to amplify natural cognitive abilities—a written list, for example, augments memory—the most powerful cognitive artifacts transform tasks so that complex computations can be carried out through simple manipulation and perception. One example is the nautical slide rule, which can be used to solve distance-rate-time problems by moving dials, aligning marks, and reading numbers, all far simpler than applying algebra and arithmetic, even with the aid of paper and pencil or a calculator. The slide rule method is also less prone to error: the computational relations among distance, rate, and time are built into the structure of the artifact, locking out many possible errors. The use of the slide rule is easily learned, and the system of person plus artifact is powerful and reliable although not readily generalizable to other task settings. Like the slide rule, most cognitive artifacts are linked to specific practices, where they enable humans to use simple abilities to produce sophisticated outcomes.

From the perspective of distributed cognition, a person using one or more cognitive artifacts constitutes a cognitive functional system for solving a particular problem. The user is the glue that binds this system together—the one who coordinates the various resources, internal and external, to produce the desired result. Different functional systems can be computationally equivalent—that is, they can start from the same inputs and produce the same outputs—yet vary greatly in the demands they place on the person. For example, multiplying two-digit numbers through mental arithmetic is difficult and prone to error. Writing a multiplication problem in a conventional form and applying a school algorithm helps keep track of intermediate results but still demands accurate recall of the procedure and the multiplication tables. Punching a sequence of buttons on a calculator or looking up the answer in a table is simple to do but requires that the specialized tool be ready at hand—more likely in a work setting where tasks often repeat. These distinct methods use different resources, place different demands on memory and mental processes, and have different propensities for error, yet all accomplish the same computation.

In real-world activity, a cognitive functional system is dynamically instantiated to solve a current problem and then dissipates as soon as the problem-solving event is over. In unusual situations, the functional system may be wholly improvised and quickly forgotten; in more familiar situations, the functional system is likely to be highly conventionalized, although always fitted to the particular circumstances. Such conventional functional systems constitute a significant portion of the curriculum in schools, universities, and trade and professional training programs.

Social Distribution of Cognition

Through orchestrated group activity, humans accomplish tasks that would overwhelm any individual, while social institutions distribute labor and expertise across groups, sustaining complex societies. From sports to science, nearly every human endeavor depends on the social coordination of activity, whether among people in close proximity or widely dispersed in time and space. How social groups are organized, how work is divided, how knowledge is distributed, and how information is communicated all have important cognitive consequences.

Fundamental to distributed cognition is the idea that a group may have cognitive properties that differ from those of the individual. A group may have greater knowledge and processing capacity and speed, enabling it to accomplish a task too complex for a single person, especially under severe time pressure. In Hutchins's study of ship navigation, the team had to fix the position of the ship and project its future position at three-minute intervals; when the circumstances were most harrowing, the interval was reduced to one minute. The team succeeded by distributing subtasks into local functional systems (individuals with specialized tools) like those discussed above and coordinating the flow of information between these systems through a distinct pattern of social interaction. This produced a global functional system for navigation that operated rapidly and reliably, and that proved to be robust in the face of changing circumstances.

How work is divided across the members of a social group matters because some divisions are more productive and robust than others. In organizing group work, it is beneficial to maximize parallel effort without violating sequential dependencies in the task (what must be done before what). If some group members are idle or must undo or redo what has already been done by others, then the system will operate inefficiently. It may also be useful to divide activity in a way that provides mutual access and monitoring, both to catch errors and to promote learning—for which some modest yet non-catastrophic rate of error is beneficial. Or it may be useful to isolate some parts of the system from potential distraction or disruption. How activity is distributed across the group partially determines how the system adapts to change, making it more flexible or brittle; a modular arrangement, for example, makes it easier to alter some parts of the system without impacting others. Social organization and the distribution of labor—both physical and cognitive—crucially affect the success of the global functional system.

Other critical social factors include the distribution of knowledge and the pattern of communication among members of a group. Overlapping knowledge supports error detection, increasing the robustness of the system, while different patterns of communication can lead to different outcomes. In Hutchins's study, the promotion of quartermasters to new jobs paralleled the flow of information during the navigation task. The result was that those performing more critical parts of the task understood how the information they received had been generated since they themselves used to perform that portion of the task. Sensory activities like sighting landmarks through a special telescope fed integrative and evaluative activities like fixing the ship's location, projecting its future position, and assessing the quality of the fix. The operation of this socially distributed system thus parallels conventional descriptions of individual cognition.

Finally, in systems of socially distributed cognition, it is not necessary, nor is it always efficient, that there be a central executive or overseer who coordinates the activities of the group; instead, the group can operate interdependently. Computational dependencies can be turned into social dependencies, so that one group member relies on another's output to perform his portion of the task; this keeps the system from halting prematurely. On the other hand, there may be times when it is helpful to have an experienced observer watch the group's activities and recommend ways to help the system operate more efficiently. Here the observer is engaged in a different activity: representing and evaluating the performance of the system—a metacognitive function.

Temporal Distribution of Cognition

Human cognition incorporates products of past activity, distributing cognition over time. Environments for human cognition are highly artificial, crafted to support certain activities and riddled with representations. These activities follow conventional social practices and incorporate artifacts provided by others often unknown or long deceased. The residua of past cognition—material and conceptual—become structuring resources for new cognitive functional systems. Human cognition is thus inherently cultural, where culture is a process that accumulates partial solutions to frequently encountered problems.

In addition to increasing the sophistication of human cognitive accomplishments over many generations, the temporal distribution of cognition also provides an immediate benefit: It reduces cognitive load by spreading complexity over time. A navigation chart, for example, represents the results of centuries of work by navigators and cartographers; this precomputation turns the chart into a powerful computational tool. A line drawn on the chart gains an immediate relation to all the information represented there; drawing two intersecting lines executes a computation that connects a navigator to the ages.

Here in the temporal distribution of cognition, the material, social, and conceptual come together. Every moment of practice resonates on three vastly different timescales: the conduct of the activity, the development of the practitioner, and the development of the practice. This is why researchers who study distributed cognition are drawn to studying cognition in real-world settings, to what Hutchins calls "cognition in the wild."

How Distributed Cognition Differs from Individual Views of Cognition

The cognitive revolution that led to information processing psychology and artificial intelligence was founded on the idea that the mind, like a computer, is a symbol processing system: the senses transduce perceptual input into symbols which are operated on by an internal logic engine, producing other symbols that are programs for action. Distributed cognition preserves the view that humans are users of symbols and that cognition is computation but dispenses with internal symbol processing as the fundamental architecture of cognition. Cognition is computation accomplished through the propagation of representational states across representational media, which may be internal or external to the individual. Representational states are propagated by bringing the media into coordination with one another. Broadening the unit of analysis to socio-technical systems actually helps make the idea of cognition as computation plausible: inputs are transformed into outputs through the operation of cognitive functional systems. The operation of these distributed systems is what is modeled by formal systems such as computers—not internal symbol processing in the head.

Implications of Distributed Cognition for Education

Because distributed cognition focuses on activity in real-world settings, most research has investigated learning in the context of work; domains include ship navigation, fleet fishing, air traffic control, and commercial aviation. Despite the limited availability of classroom-based research, distributed cognition does offer a perspective on learning that can inform classroom instruction, both for mastering conventional systems and for supporting innovation.

Distributed cognition views learning as adaptive reorganization in a functional system. This definition covers organizational learning (the activity of groups) as well as individual learning, so long as some parts of the system adapt, or are adapted, to structure in other parts. Learning may involve changes internal to the individual, changes in the world (in representations, tools, and settings), and/or changes in social interaction. Changes internal to the individual have been the focus of traditional learning theories, probably because it is the person who brings the media into coordination to accomplish the task. A broader unit of analysis, however, entails a broader understanding of what counts as learning in a cognitive system.

For students, mastering conventional systems means more than developing simple literacy and numeracy; it means learning to compose and use functional systems to reliably perform culturally valued activities. Learning to tell time from the display of hands on a clock, for example, involves learning to coordinate ideas of number, shape, and motion with structures on the clock face and with the conventions of the system of time measurement. During instruction, a teacher guides this coordination through talk, gestures, and manipulations of objects. With practice, the student becomes able to perform without this guidance. With further practice, the student begins to recognize familiar patterns and to shift strategies, for example, from counting to directly naming times; this adaptation yields a different but computationally equivalent functional system that operates more efficiently. To help students master conventional systems, familiar teaching practices of modeling, scaffolding, and reinforcement work well, the fading of material and social supports coinciding with the encouragement of independent practice.

Innovating is different in that the individual or group must use the resources at hand to compose a functional system to accomplish a novel task, where the method for doing so may not be readily apparent. In Hutchins's study, the navigation team suffered the loss of the gyrocompass while the ship was navigating a narrow channel; the team was forced to invent new procedures on the fly as the ship faced the danger of running aground. At first, the team's activity was driven almost entirely by the environment—by whatever information happened to be coming in. As individuals made changes to simplify their own activity, others adapted to these changes. Eventually, the system settled into a stable pattern—a new functional system that dissipated as soon as the crisis was over. To help students innovate, teaching practices that introduce variability into established systems or that pose novel problems are likely to work best. These should be followed by comparison and analysis of different approaches, paying particular attention to the representations used, their coordination, and any adaptations that had to be made. Other topics to discuss include the specificity or generality of the approach, its propensity for error, and the demands it places on the person using it. Distributed cognition provides a useful framework for guiding such discussion.

— *Robert F. Williams, Lawrence University*

BIBLIOGRAPHY

Educational Psychology Review, 10(1). 1998 special issue on distributed cognition.

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.

Hutchins, E. (1995). How a cockpit remembers its speeds. *Cognitive Science, 19*, 265-288.

Journal of Interactive Learning Research, 13(1). 2002 special issue on distributed cognition.

Salomon, G. (Ed.) (1993). *Distributed cognitions: psychological and educational considerations*. New York: Cambridge University Press.