Distributed cognition, representation, and affordance

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This article describes a representation-based framework of distributed cognition. This framework considers distributed cognition as a cognitive system whose structures and processes are distributed between internal and external representations, across a group of individuals, and across space and time. The major issue for distributed research, under this framework, are the distribution, transformation, and propagation of information across the components of the distributed cognitive system and how they affect the performance of the system as a whole. To demonstrate the value of this representation-based approach, the framework was used to describe and explain an important, challenging, and controversial issue — the concept of affordance.

Keywords: distributed cognition, internal and external representations, affordance

1. Introduction

Distributed cognition is a scientific discipline that is concerned with how cognitive activity is distributed across internal human minds, external cognitive artifacts, and groups of people, and how it is distributed across space and time (Hutchins 1995a, 1995b; Norman 1991; Zhang 1997a, 1997b, 1998; Zhang and Norman 1994). In this view, people's intelligent behavior results from interactions with external cognitive artifacts and with other people, and people's activities in concrete situations are guided, constrained, and to some extent, determined by the physical, cultural, and social contexts in which they are situated (Clancey1997; Suchman 1987). The unit of analysis for distributed cognition is a distributed cognitive system composed of a group of people interacting with external cognitive artifacts. Such a distributed system (e.g., the cockpit of a commercial airplane) can have cognitive properties that differ radically

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from the cognitive properties of the components, and these properties cannot be inferred from the properties of the components alone, no matter how much we know about the details of the properties of those components (Hutchins, 1995b). In general terms, we describe the components of a distributed cognitive system as internal and external representations. Internal representations are the knowledge and structure in individuals' minds; and external representations are the knowledge and structure in the external environment (Zhang 1997b; Zhang and Norman 1994).

The term "distributed cognition" has been used in different ways. In our own research and in this paper, we use it to refer to the scientific discipline that is concerned with the distribution of information and knowledge between and across internal and external representations. It does not necessarily mean "distributed knowing or distributed thinking" of a distributed system. We do not argue for or against the assertion that a distributed system has consciousness or awareness or the assertion that a distributed system can think or reason in the same way that an individual mind does. This is a philosophical question, one insightful and deep analysis of which was offered by Harnad (2005). For the purpose of studying the behavior of a distributed cognitive system it is usually sufficient to understand how information and knowledge are distributed and propagated across the various components of the distributed system.

In this paper, we first describe two types of distributed cognition: between an individual mind and an external artifact and between individual minds. Then we will show how distributed cognition can be used to offer a novel solution to a difficult and challenging issue: affordance.

2. Distributed cognition between individuals and artifacts

A wide variety of complex information processing tasks require the processing of information distributed across internal minds and external artifacts. It is the interwoven processing of internal and external information that generates much of a person's intelligent behavior. Let us consider multiplying 965 by 273 using paper and pencil. The internal representations are the meanings of individual symbols (e.g., the numerical value of the arbitrary symbol "5" is five), the addition and multiplication tables, arithmetic procedures, etc., which have to be retrieved from memory. The external representations are the shapes and positions of the symbols, the spatial relations of partial products, etc., which can be perceptually inspected from the environment. To perform this task, people need to process the information perceived from external representations and

the information retrieved from internal representations in an interwoven, integrative, and dynamic manner. Zhang and Norman (1994) developed a framework of distributed representations to account for the behavior in these types of distributed cognitive tasks.

One important aspect emphasized by distributed cognition research is that external representations are more than inputs and stimuli to the internal mind. External representations have many non-trivial properties. For many tasks, external representations are intrinsic components, without which the tasks either cease to exist or completely change in nature. Zhang (1997b) reviewed and summarized the following properties of external representations:

- Provide short-term or long-term memory aids so that memory load can be reduced.
- Provide information that can be directly perceived and used such that little effortful processing is needed to interpret and formulate the information explicitly.
- Provide knowledge and skills that are unavailable from internal representations.
- Support perceptual operators that can recognize features easily and make inferences directly.
- Anchor and structure cognitive behavior without conscious awareness.
- Change the nature of a task by generating more efficient action sequences.
- Stop time and support perceptual rehearsal to make invisible and transient information visible and sustainable.
- Aid processibility by limiting abstraction.
- Determine decision making strategies through accuracy maximization and effort minimization.

3. Distributed cognition across individuals

Cognition can also be distributed across a group of individuals. For this type of distributed cognition, there are two different views. The reductionist view considers that the cognitive properties of a group can be entirely determined by the properties of individuals. In this view, to understand group behavior, all we need is to understand the properties of individuals. In contrast, the interactionist view considers that the interactions among the individuals can produce emergent group properties that cannot be reduced to the properties of the individuals. In this view, to study group behavior, we need to examine

not only the properties of individuals but also the interactions among the individuals. Examples of emergent group properties include group affect (George 1990), collective efficacy (Bandura 1986), and transactive memory systems (Wegner 1987).

One important issue in distributed cognition across a group of individuals is the group effectiveness problem (Foushee and Helmreich 1988). A group of minds can be better than one (process gain) because in a group there are much more resources, task load and memory load are shared and distributed, errors are cross-checked, and so on. The performance of a group can also be worse than that of an individual (process loss) because in a group communication takes time, knowledge may not be shared and different strategies may be used by different individuals. This phenomenon has been shown in a clinical environment where people work face to face, sharing Tacit knowledge (Patel *et al*. 2000) and at a distance in an internet based co-laboratory (Patel et al. 1999). Using the framework of distributed representations developed by Zhang and Norman (1994), Zhang (1998) demonstrated empirically that whether two minds were better or worse than one mind depended on how the knowledge was distributed across the two minds. The issue of group effectiveness is especially important in healthcare and has received some attention recently (Patel et al. 1996).

4. Affordance as distributed dognition

Gibson's (1977, 1979) "affordance" is an intriguing, useful, but controversial concept. According to Gibson, the environment not only serves as the surfaces that separate substances from the medium in which the animals live, but also affords animals in terms of terrain, shelters, water, fire, objects, tools, animals, human displays, etc.; and there is not only information for the perception of the environment, but also information for the perception of what the environment affords. Gibson's affordance has the following properties:

- Affordances provided by the environment are what it offers, what it provides, what it furnishes, and what it invites.
- The "values" and "meanings" of things in the environment can be directly perceived. The "values" and "meanings" are external to the perceiver.
- Affordances are relative to animals. They can only be measured in ecology, but not in physics.
- An affordance is an invariant.

- Affordances are holistic. What we perceive when we look at objects are their affordances, not their dimensions and properties.
- An affordance implies complementarity of the perceiver and the environment. It is neither an objective property nor a subjective property, and at the same time it is both. It cuts across the dichotomy of subjective-objective. Affordances only make sense from a system point of view.

Gibson's affordances capture a fundamental aspect of human perception and cognition, that is, the fact that much information needed for perception and action is in the environment as invariants which can be picked up directly. Gibson's notion of affordances was developed primarily in the study of visual perception, and his affordances are basically for environmental things such as substances, media, layouts, events, etc. Gibson hinted that affordances are not only for visual perception, but also could be for biological (e.g., toxin and nutrition) and cultural (e.g., mail box) processes. However, he did not fully explore these implications. In this section, we use the concept of distributed cognition to develop a theoretical framework of affordances.

Affordances are the allowable actions specified by the environment coupled with the properties of the organism. In distributed cognition, affordances can be considered as distributed representations extended across the environment and the organism. The structures and information in the environment specify the external representation space. The physical structures of the organism and the structures and mechanisms of internal biological, perceptual, and cognitive faculties specify the internal representation space. The external and internal representations together specify the distributed representation space, which is the affordance space (Figure 1). The external and internal representation spaces can be described by either constraints or allowable actions. Constraints are the negations of allowable actions. That is, the allowable actions are those satisfying the constraints, and the constraints set the range of the allowable actions. If the external and internal representation spaces are described by constraints, then the affordances are the disjunction of the constraints of the two spaces. If the external and internal representation spaces are described by allowable actions, then the affordances are the conjunction of the allowable actions of the two spaces.

Gibson's original affordances are basically those that are specified by the relations between the physical structures of the environment and the physique of the organism (e.g., chairs afford sitting for people). Two of the fundamental properties of affordances are the complementarity of the environment and the organism and the direct, effortless pickup of affordances. These two properties

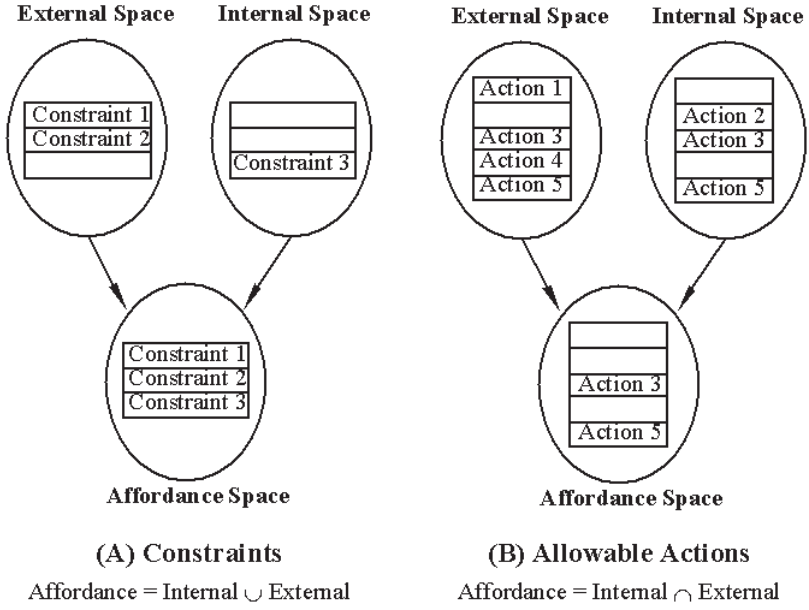

Figure 1. The distributed cognition framework of affordances. (A) The representation spaces are described by constraints. The affordance space is the *disjunction* of the external and internal representation spaces. (B) The representation spaces are described by possible actions. The affordance space is the *conjunction* of the external and internal representation spaces.

exist not only at the level of organism's body structures, but also at many other levels. The distributed cognition framework of affordance can extend Gibson's original affordances to phenomena at other levels.

Under the distributed cognition framework, affordances are distributed representations extended across external (the environment) and internal (the organism) representations. External representations belong to the environment; and internal representations belong to the organism. External representations can be at the levels of chemical processes, physical configurations, spatio-temporal layouts, and symbolic structures, which correspond to the levels for internal representations: biological mechanisms inside the body, the physique of the organism, perceptual systems, and cognitive structures and processes.

This framework can generate a categorization of affordances:

– *Biological Affordance*. Biological affordance is based on biological processes. For example, a healthy mushroom affords nutrition, while a toxic mushroom affords dying. This is at the level of biology.

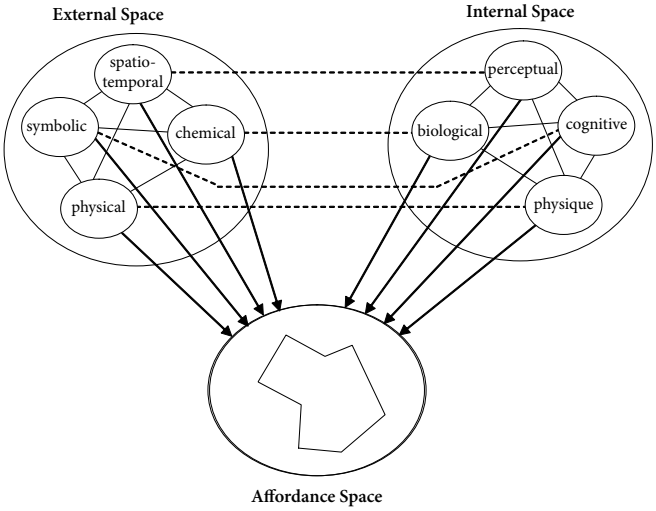

Figure 2. A categorization of affordances from the perspective of distributed cognition.

- *Physical Affordance*. Physical affordance is for tasks that are mainly constrained by physical structures. For example, the flat horizontal panel on a door can only be pushed. As another example, an open environment affords locomotion in any direction over the ground, whereas a cluttered environment affords locomotion only at opening.
- *Perceptual Affordance*. In this category, affordances are mainly provided by spatial mappings. For example, if the switches of the stovetop burners have the same spatial layout as the burners themselves, the switches provide affordances for controlling the burners. Another example is the pictorial signs for ladies' and men's restrooms in airports.
- *Cognitive Affordance*. Affordances of this type are provided by cultural conventions. For example, for traffic lights, red means "stop", yellow means "prepare to stop", and green means "go".
- *Mixed Affordance*. Many affordances are provided by a combination of more than one module. For example, shoelace affords tying shoes. This affordance is a conjunction of physical affordance and cognitive affordance: the physical property of shoelace and the knowledge of how to make a tie. The "mailbox" example given by Gibson is also a mixed affordance. A mailbox does not provide the affordance of mailing letters for a person who has no knowledge about postal systems. In this case, knowledge (cognitive affordance) and structure of a mailbox (physical affordance) are both involved in constructing the affordance for mailing and receiving letters.

5. Conclusion

Distributed cognition, in our view, is a term for a branch of cognitive science that is concerned with a special type of cognitive systems whose structures and processes are distributed between internal minds and external environment, across a group of individual minds, and across space and time. From the distribute cognition perspective, the unit of analysis is the interaction between the components of the system, not the components themselves. We applied the distributed cognition framework to address an important, challenging, and controversial issue — the concept of affordance originally proposed by Gibson.

References

Bandura, A. 1986. *Social Foundations of Thought and Action: A Social Cognitive Theory*. Englewood Cliffs, NJ: Prentice-Hall.

Clancey, W.J. 1997. *Situated Cognition: On Human Knowledge and Computer Representations*. Hillsdale, NJ: Erlbaum.

George, J.M. 1990. "Personality, affect, and behavior in groups". *Journal of Applied Psychology* 75: 107–116.

Foushee, H.C. and Helmreich, R.L. 1988. "Group interaction and flight crew performance". In E.L. Wiener and D.C. Nagel (eds), *Human Factors in Aviation.* Orlando, FL: Academic Press, 189–227.

Gibson, J.J. 1977. "The theory of affordances". In R.E. Shaw and J. Bransford (eds), *Perceiving, Acting, and Knowing*. Hillsdale, NJ: Lawrence Erlbaum, 67–82.

Gibson, J.J. 1979. *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.

Harnad, S. 2005. "Distributed processes, distributed cognizers, and collaborative cognition". *Pragmatics and Cognition* 13(3): 501–514.

Hutchins, E. 1995a. *Cognition in the Wild*. Cambridge, MA: The MIT Press.

Hutchins, E. 1995b. "How a cockpit remembers its speed". *Cognitive Science* 19: 265–288.

Norman, D.A. 1991. "Cognitive artifacts". In J.M. Carroll (ed), *Designing Interaction: Psychology at the Human–Computer Interface*. New York: Cambridge University Press, 17–38.

Patel, V.L., Cytryn, K.N., Shortliffe, E.H., and Safran, C. 2000. "The collaborative health care team: The role of individual and group expertise". *Teaching and Learning in Medicine* 12(3): 117–132.

Patel, V.L., Kaufman, D.R., Allen, V.G., Shortliffe, E.H., Cimino, J.J., and Greenes, R.A. 1999. "Toward a framework for computer-mediated collaborative design in medical informatics". *Methods of Information in Medicine* 38: 158–176.

Patel, V.L., Kaufman, D.R., and Magder, S. 1996. "The acquisition of medical expertise in complex dynamic environments". In A. Ericsson (ed), *The Road to Excellence: The Acquisition of Expert Performance in the Arts and Sciences, Sports, and Games*. Hillsdale, NJ: Lawrence Erlbaum, 127–165.

Suchman, L. 1987. *Plans and situated actions: The problem of human–machine communication*. New York: Cambridge University Press.

Wegner, D.M. 1987. "Transactive memory: A contemporary analysis of the group mind". In B. Mullen and G.R. Goethals (eds), *Theories of group behavior*. New York: Springer, 185–208.

Zhang, J. 1997a. "Distributed representation as a principle for the analysis of cockpit information displays". *International Journal of Aviation Psychology* 7: 105–121.

Zhang, J. 1997b. "The nature of external representations in problem solving". *Cognitive Science* 21: 179–217.

Zhang, J. 1998. "A distributed representation approach to group problem solving". *Journal of the American Society of Information Science* 49(9): 801–809.

Zhang, J. and Norman, D.A. 1994. "Representations in distributed cognitive tasks". *Cognitive Science* 18(1): 87–122.

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