Procedural and Declarative Knowledge

An Evolutionary Perspective

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ABSTRACT. It appears that there are resemblances in the organization of memory and the visual system, although the functions of these faculties differ considerably. In this article, the principles behind this organization are discussed. One important principle regards the distinction between declarative and procedural knowledge, between knowing *that* and knowing *how*. Declarative knowledge is considered here not as an alternative kind of knowledge, as is usually the case in theories of memory, but as part of procedural knowledge. In our view this leads to another approach with respect to the distinction. Declarative knowledge has occupied more attention in (cognitive) psychological research than can be justified on the basis of the importance of procedural knowledge for behavior. We also discuss the question whether there are other brain faculties that reflect the same organizational characteristics. We conclude with some speculations about the consequent role of consciousness in such a tentative model.

KEY WORDS: declarative knowledge, evolutionary psychology, memory, procedural knowledge, vision

Introduction: Modularity in the Human Brain

Traditionally, cognitive psychology has viewed the human mind as a general information-processing device. On this view, a human being is born with a set of general reasoning capacities that can be used when confronted with any problem. A growing number of researchers are supporting a view of the human brain as an organized collection of specialized modules, each with its own domain-specific knowledge and responses. This approach converges with the related field of knowledge known as evolutionary biology.

The human brain is the most complex system in the known universe (Edelman, 1993). This system, however, has developed according to the principles of evolution. Investigating the origins of the brain might lead to more comprehension of its functioning. Evolutionary biology can provide us with insights that can be used in this process of disclosure.

Ornstein (1991) puts it this way:

> The mind is a squadron of simpletons. It is not unified, it is not rational, it is not well designed—or designed at all. It just happened, an accumulation of innovations of the organisms that lived before us. The mind evolved, through countless animals and through countless worlds. Like the rest of biological evolution, the human mind is a collage of adaptations (the propensity to do the right thing) to different situations. Our thought is a pack of fixed routines—simpletons. (p. 2)

Complex systems emerge from simple systems through mechanisms of change and mutation. The best known, and perhaps the only, explanation for the emergence of complex functional designs in organic systems is natural selection. It follows that the brain developed according to the same principles. Therefore, the design of the brain can be expected to reflect the process of adaptation of our ancestors to their environment and the recurrent problems it brought them. There is no plausible reason to assume that the brain has evolved as a 'general-purpose problem-solver'. Additionally, evolutionary biology provides the following arguments:

1. In order to discriminate successful from unsuccessful performance, an organism must apply rules for judging success. Since there are many different problems to solve (edge perception, eating), one single rule will not do. It follows that an evolved architecture needs to consist of content-specific structures to discriminate adaptive success from failure.
2. Some problems human beings encounter cannot be solved by general problem-solving strategies, such as language acquisition.
3. Different kinds of problems ask for different kinds of solutions. If solutions for two different problems do not concur, one single solution for these two problems will always be inferior.
4. Some problems ask for courses of action that cannot be learned by a domain-general system because they depend on statistical relationships which are not observable for individual animals, for example incest avoidance.
5. A domain-general system would have to face the problem of combinatorial explosion.

These and other arguments are discussed at length by Tooby and Cosmides (1992), who argue for a rigorous functional adaptive analysis of mental modules. Following Tinbergen (1952), they suggest an approach to human behavior and mentality from four perspectives: (a) the ontogenetic and phylogenetic origins of certain behavior patterns and mental functions; (b) their physiological mechanisms (as can be discovered by, e.g., neuropsychological evidence); and (c) the adaptive functions of these behaviors and of (d) mental functions for the species at the moment of their genesis. In this article we analyze two mental functions in this way.

The central idea in the present paper is the claim that some human mental

functions have a similar organization, and that this organization reflects its emergence from simpler systems. This organizational principle supposedly exists independently of the considered functions and therefore points to a tendency of certain faculties to evolve along the same lines.

Memory

In memory research, many distinctions between different kinds of memory systems have been suggested. Most central, and the most important in the current context, is the distinction between declarative and procedural memory (Squire, 1987). It is also referred to as a distinction between knowing *that* (propositional knowledge) and knowing *how* (skills necessary for operating on the environment) (Roediger, Weldon, & Challis, 1989). This distinction only refers to long-term memory; short-term memory is a feature of declarative memory and will not be discussed here (Squire, 1987).

Procedural Memory

Procedural memory is proposed as the system containing knowledge of how to do things. This kind of knowledge guides both physical activities like cycling or swimming, and (partially) cognitive skills like playing chess or speaking in public. Usually, many trials are needed to acquire procedural knowledge, although one-trial learning does occur. These skills are hard to express verbally, if at all; the only way to show their presence is by means of performance.

It can be argued that procedural memory is relatively autonomous in relation to declarative memory in a number of ways. In certain types of amnesia, such as anterograde amnesia or Korsakoff's syndrome, patients are no longer able to collect or recollect new (declarative) facts. However, they are able to acquire new procedural skills, although sometimes slower and more painfully than normal. This is the case even when the knowledge to be acquired contains declarative components (Squire & Knowlton, 1995). An example is patient N.A., who suffered severe anterograde amnesia but learned a mirror-reading task at a normal rate (every session maintaining that he had never seen it before) (Cohen & Squire, 1980).

Other examples of learning in amnesia patients are conditioning, word complementing and the effect of priming on word recognition. All these tasks have in common that learning takes place by performance and not by conscious recollection of the experience of the learning process; in other words, these are procedural skills (Baddeley, 1990). Long-term declarative memory often is not necessary for performance (Squire & Knowlton, 1995).

This is why playing chess can be considered an example of a partial procedural skill: one gets better while practicing, but is not able to express

exactly why this is so. This phenomenon obviously has nothing to do with the declarative knowledge needed for playing chess, for surely the rules of the game do not change as one gets better.

Declarative Memory

Declarative memory is responsible for what cognitive psychologists traditionally consider to be knowledge, that is, storage of facts and events. Declarative knowledge is symbolic knowledge (Broadbent, 1989), sometimes subdivided in semantic and episodic memory (Tulving, 1985).

Declarative memory affords an individual the capacity to store associations, and to do so in a single trial (Squire & Knowlton, 1995). It stores information in propositions the truth or falsity of which can be verbalized instantly (Neely, 1989). The system contains knowledge that can be thought and spoken about explicitly. There are exceptions to this rule, however, as in the case of memory for faces; these are very difficult to describe verbally (Tulving, 1985).

Declarative knowledge can be altered under the influence of new memories. Declarative knowledge is not conscious until it is retrieved by cues such as questions. The retrieval process is not consciously accessible either; an individual can only become aware of the products of this process. It is also a very selective process. A given cue will lead to the retrieval of only a very small amount of potentially available information. Expression of declarative knowledge requires directed attention, as opposed to the expression of skills, which is automatic (Tulving, 1985).

Comparison of the Two Memory Systems

The two kinds of memory appear fundamentally different. First, there is a dissociation between them (Cohen & Squire, 1980). Second, one of them (the declarative system) is verbally expressional while the other one is not. Moreover, there are reasons to believe that procedural memory is older, both phylogenetically and ontogenetically (Bloom & Lazerson, 1988). Finally, declarative memory occupies specific regions in the brain (the medial-temporal region, parts of the diencephalic system and the hippocampus) while procedural memory does not; procedural memory is more like a technique applied when necessary than a local module, and as such it is less vulnerable to lesions (Bloom & Lazerson, 1988).

Although some evidence concerning the location of procedural memory can be found, this evidence usually is not at all convincing (see Dudai, 1989, p. 264 for some examples). Moreover, it often deals with procedural motor skills and seldom considers procedural cognitive abilities.

As pointed out before, further subdividing of declarative memory is still a matter of debate. The same goes for procedural memories.

There are many different types of learning and memory tasks which are

currently dubbed together as 'procedural', including classical conditioning, motor and perceptual skill acquisition by operant and incidental learning, and others. The proposed common denominator of these learning tasks is a certain acquired 'automaticity' in response; in all probability they represent the output of different types of brain systems. (Dudai, 1989, p. 265)

Perhaps this is why a specific location for procedural memory cannot be found.

The Visual System

Another faculty of the human brain is the visual system. The visual system itself has evolved in response to several environmental circumstances. Therefore several subsystems or modules can be expected to be part of the organization of the visual system. Current theories of vision agree on the assumption that at least two subsystems can be distinguished within the cortical part of the visual system. These subsystems are sometimes called the ventral and the dorsal stream of visual analysis. They are supposed to be concerned with, respectively, specification of 'what' is perceived in visual information and 'where' this is located. The ventral stream is assumed to be dedicated to object recognition and the dorsal stream to the perception of motion and stimulus localization. We will first discuss the basic outline of the human visual system, before turning to a more elaborate discussion of these two streams of visual analysis.

Major Connections in the Visual System

The optic nerve carries visual information from the eyes to the optic chiasm. Two neural pathways descend from the optic chiasm: the geniculostriate and the tectopulvinar pathways. In humans, the geniculostriate pathway carries about ninety percent of the visual information (Milner & Goodale, 1995). It is relayed via the lateral geniculate nucleus of the thalamus and ends in the occipital lobe.

The occipital lobe is the location of the primary visual cortex, also known as area 17, V1, area oc or the striate cortex. In primates, information from the lateral geniculate nucleus of the thalamus enters the striate cortex at level IVc. From this layer, the information is relayed upwards and downwards to the other layers, where it is analyzed according to specific features encapsulated in that information. That is, neural circuitry within the layers combines information from several ganglion cells to detect features larger than the receptive field of a single ganglion cell. Several features like orientation, movement, spatial frequency and texture of the input are extracted in this way (Coren, Ward, & Enns, 1994).

There are several kinds of cells that analyze the input (Hubel & Wiesel, 1979). However, analysis of information in the modules of the striate cortex

yields no perception; to reach this end, the information delivered by the
modules via, among others, the superior colliculi, pulvinar and the thalamus
is integrated in the extrastriate region, also called the associative visual
cortex (Zeki & Shipp, 1988). In this system, the tectopulvinar and geniculo-
lostriate pathways merge. Studies of the visual system of macaque monkeys,
which in many ways is similar to the visual system of humans, have revealed
that the associative visual cortex comprises at least 25 different maps,
arranged hierarchically. All mapping systems are specialized in filtering
particular features, like movement or color. The result of this analysis then
passes on to higher regions (Van Essen, Anderson, & Felleman, 1992).
However, no 'supervisory map' has been found that coordinates all informa-
tion yielded this way. The mutual connections between all maps act as a
cohesive entirety (Edelman, 1993).

   The two pathways differ in the amount of input they receive from two
different cytological types of retinal ganglion cells: parvo and magno
ganglion cells. These cells differ from each other in anatomy, physiology
and function. The parvosystem encodes features needed for object recogni-
tion, whereas the magnosystem is concerned with location and movement of
objects in the visual field (Maunsell, 1992). The geniculostriate pathway
receives input from both parvo and magno cells; the tectopulvinar pathway
receives input from magno cells only (Milner & Goodale, 1995). This
suggests that the function of the respective pathways is recognition and
localization (cf. Schneider, 1969).

   The associative visual area is the starting point of two streams of visual
analysis. Both streams start in the striate cortex and begin to diverge in the
extrastriate cortex. They lead to regions of the brain where additional maps
are found, called the tertiary visual areas. One is the ventral stream, the other
is the dorsal stream.

The Ventral Stream

The ventral stream is located in the temporal lobe. In the inferotemporal
cortex, neurons are found that are sensitive to size, shape, color, orientation
and direction of movement to a fair degree of specificity. In the superior
temporal cortex, neurons are found that respond to, for example, the sight of
faces, particular faces, faces moving in a particular way or only the sight
of eyes looking in a particular direction (Perrett, Mistlin, & Chitty, 1987).
Lesions in this particular part of the brain can lead to prosopagnosia, the
inability to recognize faces (De Haan, Young, & Newcombe, 1987).

   At the end of the ventral stream lies the inferior temporal cortex, where in
primates visual pattern recognition and object identification take place
(Boussaoud, Desimone, & Ungerleider, 1991; Ungerleider & Mishkin,
1982).

   Current theories suggest that the ventral stream of visual analysis is

concerned with object recognition: 'seeing what'. Removal of both temporal lobes causes visual agnosia: vision is still possible, but identifying and categorizing objects by shape is not (Warrington & James, 1988).

The Dorsal Stream

The dorsal stream is located in the parietal lobe. It appears to be concerned with analyzing and remembering relative spatial location. Bilateral damage in the parieto-occipital region leads to Balint's syndrome, which consists of three subsyndromes: optic ataxia, a deficit in reaching under visual guidance; ocular apraxia, a deficit in visual scanning (the patient is not able to maintain fixation and perceive locations of what is to be seen); and simultanagnosia, a deficit in seeing several objects at a time (Carlson, 1994).

Goodale and Milner (1992; Milner and Goodale, 1995) state that the primary function of the dorsal stream is to guide actions rather than perceive spatial locations. Therefore, it would be better to refer to the two streams as analyzing 'what' and 'how' is seen instead of 'what' and 'where'. Goodale and Milner mention two considerations regarding this conviction. First, the visual cortex of the parietal lobe is extensively connected to regions of the frontal lobe involved in controlling eye movements, reaching movements of the limbs and grasping movements of hands and fingers. Second, two of the subsyndromes of Balint's syndrome, optic ataxia and ocular apraxia, are deficits in visually guided movements. Carlson (1994) reasons that

> . . . if the primary role of the dorsal stream is to direct movements, it must be involved in location of these objects . . . in addition, it must contain information about the size and shape of objects, or else how could it control the distance between thumb and forefinger? (p. 178)

Carlson mentions the case of a patient with bilateral lesions of the anterior temporal cortex who was unable to recognize objects (name them) but who was able to say and demonstrate what to do with them (though not what they were used for). Carlson argues that in this patient, the dorsal stream and its connections with speech were intact, which is why the patient was still able to describe the use of objects: 'this interpretation is consistent with Goodale and Milner's conclusion that the dorsal[1] stream is primarily occupied with controlling movements, not simply perceiving the location of objects' (p. 179).

A third problem with the original what/where distinction is that spatial analysis is not a unitary function but exists on very different levels of visual cognition. The processes of object manipulation and of navigation, object recognition and the perception of spatial relations between objects are but a few of the different spatial problems the visual system is capable of solving (Ullman, 1995). This makes the existence of a single system of 'seeing where' highly unlikely.

The Dorsal/Ventral Distinction

Just like the geniculostriate and tectopulvinar pathways, the input to the dorsal and ventral streams of visual analysis did seem to differ in the input from magno and parvo ganglion cells. These cells differ from each other in a way that bears similarity to the differences between the streams. As said before, the parvosystem is concerned with object recognition while the magnosystem is concerned with location and movement of objects in the visual field (Maunsell, 1992). Recent investigations, however, have made clear that the parvo and magno cellular input is not as separated as had been assumed previously. It appears that both the ventral and the dorsal stream receive input from both parvo and magno ganglion cells (Goodale & Milner, 1992; Maunsell, 1992). This makes sense if one considers the fact that object recognition requires perception of spatial relationships of the object's component parts, and in order to perceive an opportunity for action, one must be able to distinguish between objects (Landau & Jackendoff, 1993).

Milner and Goodale (1995) argue that the division between seeing what and seeing how is a division based on the alleged differences in input to the ventral and dorsal streams. This input-based approach supposedly stems from a concept of vision as an analysis of visual information rather than as control of behavior. But, as pointed out before, if one wants to understand organic information-processing, one has to understand the environmental requirements in response to which this system has evolved. The visual system has not evolved to provide us with perceptual experience; it has evolved to the demands of motorical behavior. The different computations both streams perform reflect the different purposes they serve. Therefore, an output-based analysis is more appropriate as a framework for understanding the visual system.

The output requirements of the dorsal and ventral stream differ considerably. They are concerned with respectively on- and off-line aspects of visual behavior. The ventral stream constructs an object-centered representation which is kept in long-term memory while the dorsal stream is concerned with on-line guidance of behavior, which is stored in working memory, not in long-term memory, because the exact parameters of action differ across situations and are relevant only in the particular situation one is in at the time.

Procedural Knowledge

The ventral stream of visual analysis is primarily concerned with object recognition. The dorsal stream is concerned not with seeing where but mainly with seeing how. This division bears a strong correspondence to the division between declarative and procedural memory. Although the anatomical correlates of these divisions differ considerably, the functional corres-

pondence is striking. These parallels unite a physiological approach with a psychological view on vision and its relation to action upon the environment. We will now turn to a more elaborate discussion of the concept of 'procedural vision'.

Procedural Vision

J.J. Gibson (1968, 1979) is the founder of what is canonically called 'direct perception'. Direct perception is the view that in perception there is no need to assume any higher-order processing or internal representations involved in perception. The environment contains sufficient information to give rise to visual perception. The theory of direct perception has been developed in response to serious problems that arose in the traditional, physical, approach to vision. One of the core assumptions in Gibson's theory is the assumption that the most relevant features an animal perceives are what the world affords an animal to do.

> The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. . . . Perhaps the composition and layout of surfaces constitute what they afford. If so, to perceive them is to perceive what they afford. This is a radical hypothesis, for it implies that the 'values' and 'meanings' of things in the environment can be directly perceived. (Gibson, 1979, p. 127)

Accordingly, what affordances are perceived is unique for each animal. If what is perceived is meaningful, it is meaningful relative to an individual organism. Of course, members of the same species more often perceive the same affordances of objects than individuals of different species. Gibson suggests that the ecological concept of 'niche' is to be seen as the set of affordances for an individual member of a species.

Because an affordance is not a phenomenal object, it changes as an animal changes (e.g. grows, or develops physical handicaps). However, it does not change as the *need* of an animal changes. The affordance of a flat surface is that it can be walked upon, even if an observer is watching the surface while sitting in a tree. This is a major difference between the concept of affordance and the concept of valence.

Although Gibson avoided physiological or neurological considerations, we speculate that his theory refers to the dorsal stream of visual analysis, discussed in the previous section, at least as far as it concerns animals with a cortex (remember the dorsal stream is a cortical stream). That is, it concerns seeing how. In our view, the theory of procedural vision—although it originates in the neurological considerations Gibson would have avoided—sheds new light on the discussion on affordances, and, vice versa, is supported by Gibson's untimely discovery.

Our approach converges with the views of Leslie (1994) on the direct perception of agency. Leslie distinguishes three subsystems of visual analysis: one is concerned with the mechanical properties of an object; one is concerned with the actional properties of an object; and a third is concerned with cognitive properties. The first of these is called ToBy (Theory of Body mechanism). It comprises two different parts of the visual system.

Leslie (1994) suggests that 'ToBy has two principal inputs from vision: one from a three-dimensional object recognition device, and one from motion analysis systems, including the Michotte module' (p. 127). In Leslie's analysis, the processes involved in shape representation are distinct from those involved in the representation of use and function of an object.

> In brain-damaged patients either kind of information may be impaired independently of the other. The visual three-dimensional object recognition device is concerned purely with the 'geometry' of objects. . . . Specifically, visual object recognition is not concerned with the mechanical properties of the object, and therefore is not concerned with whether the object is cohesive, substantial, mechanically bounded, or numerically identical over time. (p. 128)

Leslie refers to the output of the visual object recognition module as the 'purely visual object' to stress the distinction between an object-recognized-by-shape and an object-constituted-mechanically. The Michotte module is a part of ToBy. It is responsible for the perceptual illusion of causality when, for example, two patches of light simulate the billiard ball launching event. This supports the view that procedural and purely visual properties make use of distinguishable systems in the brain. We propose that these are the dorsal and ventral systems, respectively.

That the perception of the purely visual object is dissociated from the mechanical properties of the object can also be shown by the fact that in visual imagination and in vision for object recognition it is possible to violate the solidity constraint. Although objects cannot pass through one another, this can be perceived, for example by means of certain visual illusions. In the stereoscopic illusion produced by a Pulfrich double pendulum, a person sees two solid rods pass through one another. In the window frame illusion, Ames (1951) showed that a solid bar can be made to appear as if it passes through the stills of a window frame if the frame is constructed asymmetrically in the vertical plane. Mechanical constraints clearly do not belong to the realm of object recognition.

It seems clear that what Leslie calls the 'three-dimensional object recognition device' and 'motion analysis systems' parallel the ventral and dorsal stream of visual analysis, respectively. Leslie illustrates the fact that the dorsal stream is not (only) concerned with the relative spatial location of objects but (also) with their (mechanical) properties. This last notion fits nicely with Gibson's notion of the perception of affordance.

The three approaches discussed, 'seeing how', 'affordances' and 'motion

analysis systems', all seem to refer to what we shall, from here on, call procedural vision. The underlying principle is (the often direct) perception of opportunities for action in the visible environment of an animal.

An Evolutionary Perspective of Memory

In the preceding pages it has been argued that in vision as well as in memory a functional distinction can be made between procedural and declarative knowledge. This distinction, however, might not be as clear-cut as has been suggested up to now. It is our conviction that declarative knowledge is not so much an independent faculty of memory as it is an outgrowth of procedural knowledge. We will discuss several considerations that led us to that conviction.

Procedural memory is older than declarative memory. Phylogenetically, this can be shown by the fact that declarative learning only occurs in higher animals, if not human beings. Ontogenetically, this can be shown by the fact that children begin to learn and remember procedures before they do facts (Bloom & Lazerson, 1988). Also, procedural skills are more important for survival than declarative facts (Dudai, 1989). Therefore, it is not reasonable to assume that knowledge of facts evolved before the knowledge of skills.

Another argument has to do with recent developments in the research on neural networks. By their very nature, neural networks are suited for the modeling of procedural knowledge. When an input is fed to a network, it 'knows' how to react. This knowledge is implicit and can only be made explicit by the analysis of hidden units. Procedural knowledge is a concept of a dynamic process that cannot be represented validly by means of a sequential rule system (Bechtel & Abrahamsen, 1991). Networks have been designed that are able to assimilate concepts which were traditionally considered to be propositional (i.e. declarative) systems, for instance certain rudimentary language structures (see Seidenberg, 1992, for an example) and logical inferences (Bechtel & Abrahamsen, 1991). In psychologically relatively plausible systems that operate on these classes of input, propositions are considered as a description of the outcome of a process, not as a description of the process itself.

Finally, some considerations concerning one-trial learning are of interest here. One-trial learning seems a typical feature of declarative memory: one is told something once and knows it. This fits with the traditional view of declarative knowledge as a propositional system: a new proposition is added to the existing collection. Mathematical principles are a typical example. However, tasks of this type also ask for practice. The explicit knowledge that '+' means 'add together' is a starting point from where much practice is needed before one actually masters the skill of addition. To know what '+' means is declarative knowledge; being able to add is procedural knowledge. The neural network of Bechtel and Abrahamsen (1991), mentioned above,

has never been told explicitly what a logical inference is. However, it still is able to make them, although it takes 576,000 trials to succeed. It seems that the starting point of one-trial learning is not always a necessary condition, only a very efficient one that in some cases can be replaced by much more practice.

In the context of human declarative memory, one-trial learning implies that a fact is comprehended after one presentation. But it is also possible to know how to do something after one presentation. Baddeley (1990) provides an example of this one-trial procedural learning:

> It was his custom on morning rounds to shake hands with his patients; on one occasion, when shaking hands with a lady suffering from Korsakoff's Syndrome, a form of amnesia typically associated with alcoholism, he secreted a pin in his hand. The following morning the lady refused to shake hands with him, but was unable to say exactly why! She appeared to have learnt to avoid shaking hands, but had no recollection of the incident that had provoked it. (p. 207)

If this patient was told not to shake hands with the doctor, she would have forgotten it the next day.

In this case, it was the emotion associated with the triggering event that caused one-trial procedural learning. The evolutionary value of such a system is evident. It is not valid to assume one-trial learning only occurred with the evolution of declarative memory. Some birds learn to fly on a single occasion. Significant events, such as taste-aversion conditioning in rats, are subject to one-trial learning (Garcia, Kimmeldorf, & Koelling, 1955; Squire & Knowlton, 1995).

To summarize, we argue that declarative memory evolved from procedural memory, and is more or less a part of it. Some of its aspects might even be reduced to procedural memory. It is both phylogenetically and ontogenetically younger than procedural memory, it has proved possible to model declarative knowledge in procedural systems (neural networks), and in some cases one-trial learning is possible within the procedural system. These arguments suggest that declarative knowledge is made possible by procedural knowledge; declarative knowledge could be considered a special case of procedural knowledge. As Crowder (1989) observes:

> In relation to procedural and declarative memory, we talk as if two systems have been isolated, but really there is only one element—the declarative encoding of temporal context—that is separate from all the other diverse procedural formats. Each of the latter is 'stored' in its processing locus in the brain. Procedural memory is really an umbrella term for processing residues of all sorts, depending on the mode of original information-processing. . . . (pp. 289–290)

Carlson (1994) makes a similar point:

> The hippocampal formation enables us to learn the *relation* between the

> stimuli that were present at the time and the sequence of events that occurred during the episode. As we saw, people with anterograde amnesia can form perceptual memories. As the priming studies have shown, once they see something, they are more likely to recognize it later. But their perceptual memories are isolated; the memories of individual objects and events are not tied together. Thus, seeing a particular person does not remind them of other times they have seen that person or of the things they have done together. Anterograde amnesia appears to be a loss of the ability to learn about the relations among stimuli, including the order of their occurrence in time. (p. 490)

So it seems that the term 'procedural memory' is misleading. Nearly all learning- and memory-phenomena are procedural. Pure declarative knowledge is the exception rather than the rule. (See also Willingham & Preuss, 1995.)

A final observation with regard to declarative memory stems from the phenomenon of category-specific impairments in semantic memory. A double dissociation has been found in brain-damaged patients between their knowledge of respectively living (animals, fruits) and non-living (tools, clothes) things. Saffran and Schwartz (1994) argue that this deficit actually reflects not a distinction between living and non-living things but a distinction between perceptual and functional characteristics of members of the impaired categories. The ground for distinguishing between two animals as similar as a leopard and a panther is the difference in visual characteristics, while the ground for distinguishing between two tools is their different functions. Once more, a difference between action and perception is found in a presumably single system. Category-specific impairment for functional attributes of objects is not a deficit of procedural memory since tool use is intact. In terms of the present theory, this could imply that even within a part of declarative memory (semantic memory) procedural aspects are a fundamental part of the system. However, to draw any conclusions from this speculation would be premature until it becomes clearer what memory system exactly is damaged in these cases and how it connects with other systems.

Exactly how evolution of brains and brain modules proceeds is unknown. However, there is no reason to assume that the evolution of memory and of the visual system has the same background, for these faculties are concerned with quite different tasks. Taken together, the present theory states that in both vision and memory, a declarative subfaculty is part of the outcome, and that both systems are far more procedural in nature than hitherto assumed.

A tentative conclusion that can be made considering all this is that the procedural/declarative distribution is a feature of certain brain modules that exist independently of the content of those very brain modules. The distribution is a principle that supposes an organization of a certain kind in certain brain modules. If this hypothesis is valid, then an imbalance in the

attention of cognitive psychologists and neuroscientists given to the pro-
cedural subsystem and the declarative subsystem can be found in the visual
system as well as in the memory system. We therefore now discuss several
considerations concerning the evolution of vision.

An Evolutionary Perspective of Vision

Procedural vision is phylogenetically older than declarative vision. It is the
magnocellular input that is responsible for the features of procedural vision:
sensitivity to movement, motion detection and temporal analysis. Parvo-
cellular input is a more recent evolutionary development (Livingstone &
Hubel, 1987). Moreover, object recognition is a function occurring only in
'higher' animals. It seems reasonable to assume that if some characteristic of
an organism is ontogenetically older than some other characteristic, this first
characteristic is also phylogenetically older than the other characteristic.

   There are empirical indications that procedural vision is ontogenetically
older than declarative vision (Spelke, Vishton, & Von Hofsten, 1995). First,
an infant's perception is sensitive to certain constraints on object motion.
The following constraints have been found to guide object perception:
objects move as connected wholes; as bounded wholes; on continuous and
unobstructed paths. Second, the processes that guide object perception,
needed for object recognition, occur relatively late in the development of
visual analysis. Also, an infant's perception of the unity of objects does not
depend on color, texture, shape or alignment relations of the object. This
corresponds to Gibson's view of the perception of the affordances of an
object as an invariant combination of variables, apart from relatively
irrelevant details (e.g. the color of that object).

   Thus, Spelke et al. (1995) state that

> . . . cognition does not appear to depend on a single, homogeneous
> knowledge system but rather on a set of distinct systems for representing
> the world. The . . . representational system underlying object perception
> and physical reasoning is distinct from the representational system or
> systems underlying many object-directed actions. (p. 177)

   Thus, a key feature of procedural vision, as opposed to declarative vision,
is its dynamic nature. Procedural vision is by its very nature concerned with
perception of dynamic processes. Static cognition can be found in the
declarative cognitive functions of the brain. In vision, this comes down to
object recognition. But the process of object recognition itself is not static
either. Perception exists by virtue of movement. If, by artificial means, an
object is kept stationary relative to the retina, perception breaks down within
three seconds (Yarbus, 1967). In normal conditions the eyes show very rapid
movements, identical in both eyes, called saccadic movements. The main
function of saccadic movement is to change the point of fixation of the eyes
(thus preventing perception from breaking down) and to direct the most

sensitive region of the retina, the fovea, to places of interest in the visual field (Yarbus, 1967).

In a series of experiments carried out by Freyd (1983), it was shown that, even when viewing static stimuli, people perceive the dynamics in that stimulus and use this information in order to recognize static forms. One of these experiments is especially interesting in the current context. In this experiment, people were taught to write newly designed letters. In identifying distorted versions of these letters, they used cues as to how the letters had been written. This was shown by the fact that recognition of these letters was faster when the distortion was consistent with the drawing procedure they had been taught than recognition of letters equally distorted but inconsistent with the drawing procedure. These people used procedural vision.

A convincing example of the necessity of dynamics in perception is the work of Johansson (1973). Johansson produced films of 'biological motion', by attaching lights to the joints of an actor, letting the actor move and processing the film in such a way that only the lights could be seen. If one still frame of such a film is shown, only a meaningless group of dots is perceived. But as the film is set in motion, after 100 milliseconds the pattern of light is identified as a human being, including the posture, gait and particular activity of that human being. It turns out that movement of a stimulus is a very powerful cue used to confer organization.

What happens when object perception fails? Milner and Goodale (1995) provide a thorough elaboration of their viewpoint that the primary goal of the dorsal stream of visual analysis is to guide action. They describe the case of a patient, D.F., whose ventral stream had been severely damaged due to asphyxiation and who came to suffer visual-form agnosia as a consequence. D.F. was no longer capable of perceiving the shape of an object. She was, however, capable of engaging certain actions towards the same object that did exploit cues about the shape of that object, such as grasping.

Another deficiency of the visual system that is relevant to the present argument is blindsight. This pathology is the result of damage to V1. It causes loss of conscious visual perception, 'awareness that'. It does not, however, lead to a loss of opportunity to use visual information in order to guide action. This is shown by the fact that blindsighted people usually are capable of localizing points of light in their damaged visual field, although they cannot perceive those points of lights. Moreover, their accuracy in localizing depends on the nature of the response. Localization is more accurate if the patient is allowed to point to the light than if the patient is only allowed to look at the stimulus. Milner and Goodale (1995) theorize that area V1 provides input for all of the ventral stream but not for all of the dorsal stream. The dorsal stream also has input from several subcortical structures such as the superior colliculli. It follows that part of the dorsal

stream is still intact in blindsighted people, and that it is this cortical structure that is responsible for the capacities of these people.

The combination of these observations suggest that procedural vision is older than declarative vision, and that it has been more important during the evolution of our ancestors than declarative vision. As in memory, the declarative part of the system might have bootstrapped on the original, procedural system. This is not to say that declarative vision is unimportant in humans; however, it *is* to say that the role of procedural vision must not be underestimated.

Discussion

In light of the foregoing discussion it can be speculated that an important purpose of consciousness in general, and declarative knowledge in particular, is the possibility it provides of decontextualization. To perceive an object independently of its context allows an organism to perceive abstract (declarative) properties of that object and thus to assign new properties to it. The function of an object is an example of an abstract property of that object. The function of an object, as opposed to the affordance of an object, exists independently of an observer. Affordance is view-based, short-term perception. When the orientation of an object changes, its affordances change, but its function stays the same. Perceiving the function of an object is based on the perception of declarative attributes of an object. That is, it is object-based. Perception of affordance, however, is viewer-based: it exists in interaction between organism and object. Also, a person or persons can consciously decide as to what the function of a particular object is: something can be a work of art, a book-end or a paper-weight, depending on the perspective of the user. The affordance of an object is not something that one can consciously decide to change.

The theory of procedural vision makes it clear that affordance might be best defined as a visually specified opportunity for motor action. This restriction affords some new interpretations of Gibson's approach. Gibson speaks of the affordances of contours (hiding things behind each other) as well as animals (danger, food, communication). Following the evolutionary viewpoint outlined in the introduction, it is not expected that these attributes are all perceived by a single system. Also, a cultural influence can be expected when one is speaking of affordances of artificial objects (tools) and the perception of certain affordances can be learned. A keyboard, for example, provides different affordances for a novice and an expert typist.

Thus, a tentative conclusion about Gibson's theory is that he was right about the importance of dynamics in perception but that he paid insufficient attention to declarative vision. The perception of affordance can be mediated by declarative knowledge and object recognition even more so.

For instance, it is clear that some objects do have 'more affordance' than

others. It is easy to see what the affordance of a hammer is, but the affordance of a computer (information-processing) is not perceivable. We suspect this might well be the reason as to why working with computers is so difficult to learn. A computer is a much more complex object than a hammer, but the lack of affordance certainly does not make it more comprehensible. It is possible to make this complexity more comprehensible by enlarging the affordance. Thus the perception of function is mediated by the perception of affordance. To understand function perception, one must understand the parameters of affordance.

Other brain functions, such as language, might reflect the same organizational characteristics as do memory and vision in the way discussed above. This possibility can enhance the understanding of the structure of these other mind modules (e.g. Howard, 1987; Schacter, McAndrews, & Moscovitch, 1988).

Conclusion

It has been argued that memory and vision have significant features of their organization in parallel, although their functions differ considerably. This could indicate that there is a common principle along which the evolution of the brain proceeds. This organization also implies a larger role for procedural knowledge in the total knowledge-base than hitherto assumed. This is not to say that declarative memory is unimportant in understanding human behavior and human knowledge. What we *do* imply is that the role of procedural knowledge must not be neglected. Some suggestions for new directions of research can be drawn from the foregoing. First, the division between procedural and declarative knowledge in memory and in vision may occur in other modules of the mind as well. Second, further research in the cognitive sciences should concentrate more on procedural knowledge and its relation (supposedly continuous) with declarative knowledge. In artificial-intelligence research one can see this already happening in research methods such as robotics, artificial life and genetic algorithms.

Third, more insight can be gained by analyzing the way the mechanisms for declarative knowledge evolved from those dedicated to procedural knowledge. This analysis should concentrate of the functions both forms of knowledge must have had for the hunter-gatherers we (still) are in terms of our evolutionary background, and the adaptation problems this implied. What problems are solved better by possessing declarative functions on top of procedural functions?

All in all this implies studying organismal functions from an evolutionary perspective. We have tried to show the advantages of this approach. That is, when one pays attention to the adaptive value of certain functions—adaptive in the evolutionary sense—it often becomes clear not only why the functions have the architecture they have, but also why they have the peculiarities they

have. Thus, we tried to point out that originally the primary function of (visual) perception was the guidance of action. The consequence of this view must be that the procedural aspects of perception are studied more prominently than hitherto has been done.

Note

1. The original phrase was '. . . that the ventral stream is primarily', but this is clearly a mistake.

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