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Study of memory: processes and systems

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A dozen or so years ago I wrote a paper under the title, 'How many memory systems are there?' It consisted of three sections. In the first I presented some pretheoretical reasons for hypothesizing the existence of multiple memory systems, in the second I described a ternary classification scheme of memory, and in the third I discussed the nature and logic of evidence for multiple systems (Tulving 1985*a*, p.385).

In the final section of the paper I observed that, 'The puzzle of memory systems is not and will not be an easy one to solve. Many difficulties have to be overcome before we can expect more rapid progress' (Tulving 1985*a*, p.395). I mentioned some of the sources of frustration there and then, and have discussed others elsewhere (Tulving 1986, 1993). One difficulty that I did not anticipate was the long-lasting vehement opposition to the simple idea of multiple memory systems. Had anyone predicted at the time that ten or fifteen years later we would still be arguing about the issue, or assembling opposite views under the heading of 'single versus multiple systems of memory', as witnessed by the present volume, I would not have believed it. I too know, of course, that we scientists love to hate new ideas (Barber 1961), and that we routinely resist facts that do not fit into whatever comfortable framework we have managed to adopt or to construct. But time and time again the history of science shows that eventually all relevant facts and worthwhile ideas do get accepted. So, what is holding up the advent of multiple memory systems?

Progress, of course, has occurred. More and more cognitive students of memory seem to be willing to go as far as to accept the idea that perhaps there are indeed *two* different 'kinds' of memory. Then, faced with a number of differently labelled dichotomies—declarative versus procedural, episodic versus semantic, controlled versus automatic, conscious versus unconscious, intentional versus unintentional, explicit versus implicit, hippocampally based versus non-hippocampally based, and several others—many of them get cold feet and immediately seek safety again, this time in a dichotomy. They do it in one of two ways. Some try to figure out which of the many dichotomies is the 'right' one, on the interesting assumption that if one dichotomy is valid then all others are invalid. Others use the good old levelling treatment and force all the existing dichotomies into a single overarching dichotomy, and try to be happy with that.

Going from a unitary system to two is progress, of course, but far too timid. Even if we did not have all the facts that point to more than two memory systems we should eagerly explore the possibility that the real number is larger. Although it is true that scientists frequently begin their efforts at classification by taking a whole and dividing into just two parts, everyone knows that Nature herself abhors dichotomies as much as she abhors a vacuum.

In this chapter, the term 'multiple' in the expression 'multiple memory systems' means 'an as yet unknown number that is probably larger than four', because we already have reasons to distinguish between at least four long-term systems (Schacter and Tulving 1994). Here I explain what I mean by the expression, how the view it represents differs from the 'unitarian' view of memory, and why I think it makes a better description of nature than the single-system view.

First, however, we have to be very clear about what it is that we are debating in this volume. There happen to be two rather closely related issues, easy to confuse with each other. One of these is under scrutiny here whereas the other is not. The issue that is being discussed here has to do with single versus multiple memory systems. The related issue that is *not* being discussed has to do with memory processes versus memory systems. Unless we clearly distinguish between the two, we will be wasting a lot of time on an irrelevancy, perhaps even without realizing that we are doing so.

The idea of the opposition between 'processes' and 'systems' is a false belief. It probably came about because process-oriented students of memory have tended to line up under the banner of unitary memory and the distinction between two different issues became blurred. Thus the process-oriented unitary view of memory came to be contrasted with the multiple systems view, leading some observers into thinking that there exists a conflict of 'processes versus systems (Foster and Jelicic, Chapter 1 this volume; Masson and Graf 1993, p.5). The idea was that there are two opposing camps: (i) one whose members explain phenomena of memory in terms of processes and their interactions within the general framework of unitary memory, and (ii) another whose members eschew process-based explanations and explain phenomena of memory in terms of the operations of multiple systems. I argue in this chapter that there is no controversy between process views and systems views of memory. The controversy is about unitary versus multiple memory systems.

The remainder of this chapter is organized into three main parts. The first one spells out the differences between process-oriented versus systems-oriented approaches to the study of memory, and explains why these approaches are not, and cannot be, in conflict. The second describes and illustrates the differences between unitary versus multiple memory theories, and shows why they necessarily must be in conflict. The third describes some critical empirical findings that converted me from being a faithful unitarian to a believer in multiple memory systems. The essay concludes with the prediction that the future belongs to multiple memory systems.

COGNITIVE AND NEUROCOGNITIVE APPROACHES TO THE STUDY OF MEMORY

For a long time there was only one general orientation to the study of learning and memory in psychology. Beginning with Ebbinghaus it went through various changes, some more substantial and some less so, but its essence stayed more or less the same for almost a hundred years. Gradually, however, the study of memory expanded beyond its original boundaries, and today it is possible to think of at least two somewhat different approaches, or orientations, to the study of memory. I refer to them as 'cognitive' and 'neurocognitive.' This section of the chapter describes the two, beginning with their working definitions.

The *cognitive approach* is a psychologically inspired approach to the epistemological explanation of the mechanisms underlying cognitive processes involved in a wide variety of memory tasks, on the basis of empirical evidence obtained from controlled experiments with normal human subjects interpreted in mentalistic (information processing) terms, all aimed at the construction of theories and models of memory. Researchers within the cognitive tradition tend to stay aloof from, and frequently do not approve of, the kinds of pursuits conducted under the neurocognitive orientation.

The *neurocognitive approach* is a biologically inspired approach to the determination of the ontology and organization of functioning neurocognitive structures that comprise memory, on the basis of a wide range of empirical evidence, including studies of cognitive consequences of brain damage interpreted in reductionist terms, all aimed at a natural classification of memory. The neurocognitive approach embraces the fact of different memory processes. It also allows, and approves of, the kinds of pursuits conducted under the cognitive orientation.

These working definitions are presented in the form of two check lists in Table 2.1. The key words in the table should not be taken terribly seriously, but they do convey the general flavour of the two approaches.

Scientists who study memory from the cognitive perspective get their inspiration from watching people behave and from reading psychological accounts of behaviour, whereas those who study memory from the neurocognitive perspective get their ideas from psychology and other branches of biology. Cognitive researchers typically begin with individual observations of effects of variables and their interrelations on memory performance and then proceed to more comprehensive theories: neurocognitive researchers frequently begin with broad ideas about the

Table 2.1 Two approaches to the study of memory

Cognitive	Neurocognitive
Psychological	Biological
Epistemological	Ontological
Models; causes	Organization; classification
Explanatory	Descriptive
Predictions	No predictions
Human adults	'Higher' animals
Memory tasks	Memory systems
Mentalistic	Reductionistic
Cognitive processes	Brain/mind correlations
Behaviour	Brain lesions; neuroimaging

nature of memory and then check the validity of these ideas empirically. Cognitive research is epistemological in spirit: it seeks to understand the causes of the phenomena of interest. Conversely, neurocognitive research is ontological in spirit: it seeks to find out what memory is and how it functions. Cognitive researchers strive after explanation of phenomena in terms of mechanisms, and thrive on what are called 'predictions'; neurocognitive researchers attempt to describe what there is in nature and how it is organized, they are less keen on predictions. Like cognitive researchers, neurocognitive researchers are interested in the memory of healthy human adults, but they cast their nets much wider. In the activities of cognitive theorists memory tasks play a pivotal role; in the activities of neurocognitive theorists tasks are also important, but so are the origins, development, and the nature of the general brain/mind capability that we call memory. The orientation of the cognitive research is largely mentalistic, and its practitioners want to understand their subject matter in terms of cognitive processes; the orientation of neurocognitive research goes beyond mentalism to reductionism, and its practitioners are equally interested in understanding their subject matter in terms of the relation between cognitive and brain processes†. While cognitive theorists are perfectly happy considering only behavioural indices of memory performance, neurocognitive theorists add to behavioural indices those of neural happenings, measures derived from electrophysiological recording and functional neuroimaging.

Although the two orientations as described necessarily have fuzzy boundaries, it is not especially difficult to classify particular theorists or theories, and particular research programmes, either over historical time or at present, in terms of the two orientations. Thus, a nice prototypical illustration of the cognitive approach is that taken by Bower (1996), who describes an extension of a 'traditional memory theory' (p.27) that explains a variety of explicit and implicit memory phenomena, as well as global amnesia, without invoking multiple memory systems. A fine example of the neurocognitive approach is provided by Schacter (1992) who looks at many of the same issues as does Bower (1996). And an excellent example of an approach that fits somewhere between the two extremes is Johnson's (1993) MEM model.

Embeddedness and complementarity

The relationship between the two orientations is one of 'embeddedness': the neurocognitive approach includes but transcends the cognitive approach. It accepts the tenets and practices of the cognitive approach, and then reaches out farther. Thus, neurocognitive researchers accept the idea that memory phenomena can be explained in terms of psychologically conceived mechanisms or processes, and that

† Because of the explosive reaction that the term 'reductionism' frequently causes in the souls of many cognitive psychologists, let me hasten to say here that the 'reductionism' in the present context is benign. It is best thought of as what Bunge and Ardila (1987, p.52) refer to as 'ontological reductionism,' that is, an acknowledgement of the fact that the mind exists by virtue of emergent properties of the brain. 'Mentalistic' in Table 2.1 may also look suspicious, but should be taken in the sense of 'scientific mentalism' (Bunge and Ardila 1987, p.52).

it is possible to construct purely psychological theories of memory. Neurocognitive researchers make a great deal use of the data collected by cognitive researchers, even if they sometimes use the data for different purposes. But neurocognitive 'types' also believe that there is more to the study of memory than what the cognitive researchers are interested in. They take for granted that memory phenomena can be explained in a number of ways—cognitively, developmentally, in light of the evolution, and in terms of underlying physiological mechanisms—and that these different accounts are complementary rather than competing. They take it as a self-evident truth that useful lessons for understanding memory can be learned from work with children, or non-human animals, or brain-damaged neurological patients, or people under the influence of psychoactive drugs. Finally they believe that it is possible and worthwhile to construct theories, although they also ask whether the theories are true.

The points I have made illustrate what I mean by the relation of embeddedness between the two approaches. In terms of the listing of the properties of the two in Table 2.1, we can say that whereas the cognitive approach can be sketched in terms of the key words in the left-hand column, the neurocognitive approach is characterized by the entries in *both* columns.

Considering objectively the relationship between the two approaches, one should find it easy to conclude that they are complementary (Hayman and Tulving 1989; Schacter 1992). Either approach would be impoverished without the other, each adds value to the other, and the two orientations together point to a more powerful and more promising direction in which to seek understanding of memory than either one could accomplish alone. This is why eventually the two orientations can be expected to merge into one (Kelley and Lindsay 1996; Roediger and McDermott 1993).

If one accepts the idea that the two approaches complement each other, the conclusion naturally follows that there is no necessary conflict between them. If so, there is no room in the ongoing debates about memory, or at least there should not be, for expressions such as 'systems versus processes'. Earlier slips can be written off as simply reflecting the growing pains of our young discipline.

UNITARY VERSUS MULTIPLE MEMORY SYSTEMS

There does exist a real conflict, and a real controversy, and it has to do with unitary versus multiple systems. We turn to this side of the story next.

Memory's unitarianism

Memory's unitarianism (hence simply 'unitarianism') refers to a pretheoretical framework or orientation that holds memory to be an indivisible complex entity. It is one faculty, or capacity, or capability, or mode of information processing, or system.

Unitarianism has had a long and illustrious history, having ruled unopposed from the very beginnings of the experimental study of learning and memory to the recent past. It evolved out of a perfectly reasonable and justifiable framework for the psychological study of learning, including verbal learning. The framework was initially created and shaped by the fact that in most languages there exists only a single term for a concept such as learning, and only a single term for memory. It was easy enough for early philosophers to raise questions about, and for early psychologists to do experiments on, something that has a label, such as 'memory', but difficult, or even impossible, to do so with unnamed and therefore non-existent entities.

Whatever the reasons for the dogma of unitary learning, or unitary memory, the tacit assumption was so prevalent that it was seldom articulated, and, as is always the case with undifferentiated ubiquities, it had no name. It was smoothly passed from generation to generation of psychological students of memory by mental osmosis.

Only seldom was the credo of unitary learning expressed, but whenever it was done, the assertion was succinct:

> All learning is essentially of a kind—the modification of behavior as the result of repeated stimulation under specified conditions. (Hunter 1934, p.497).

The central tenet of unitarianism was widely accepted, seldom discussed, and almost never questioned. (For occasional, failed attempts at rebellion, see Schacter and Tulving (1994).) When it was put under 'official scrutiny', as happened on the rare occasion of a conference in 1962 that Arthur Melton had organized to consider the taxonomy of learning, unitarianism was reaffirmed in ringing terms:

> Are we to accept a conclusion that we will have different principles of learning for different species? Most of us would not accept this any more than we would accept the idea that we will have fundamentally different principles for different forms of human learning. (Underwood 1964, p.74).

When the field of verbal learning, under the impact of the 'cognitive revolution', was transmuted into the field of memory, many practices, procedures, and assumptions changed, but the pretheoretical orientation of unitarianism did not. (For an eyewitness account of that transition see Tulving and Madigan (1970).) The reason for its survival presumably was simple: no good grounds existed for questioning the unity of (long-term) memory. Under these conditions it was difficult to even think of the idea of non-unitary memory in the abstract.

Multiple systems

The idea of multiple systems emerged slowly and initially imperceptibly. It is possible to trace the idea as such back to the nineteenth century, although the apparently unstoppable onslaught of the current ideas had its origins in the recent past (Schacter and Tulving 1994.)

What does 'multiple systems' mean? How does it differ from the view of a unitary system? Not surprisingly, there is as yet no perfect agreement among neurocognitive theorists as to the best way of characterizing systems. Tentative suggestions have been offered by a number of authors (Cohen 1984; Eichenbaum 1994; Nadel 1994; Schacter and Tulving 1994; Sherry and Schacter 1987; Tulving 1985*a*; Weiskrantz 1987), but the search for a generally acceptable conceptualization of systems continues.

Here I can only express my own understanding of the idea of multiple memory systems. It is closely related to what Bunge and Ardila (1987) have discussed under the label of the brain/mind 'identity hypothesis'. The hypothesis comprises a positive assertion—all mental events are brain events, or brain activities—and a negative one—mental events are not 'represented' in the brain. Expressions such as 'representation', or 'memory trace', or 'neural substrate', may be used, as long as we realize that they are metaphorical only. This basic 'psychobiological perspective'—today Bunge and Ardila might have said 'neurocognitive perspective'—leads easily to the question of how the brain/mind is organized, and to the idea that it is organized in the form of interacting systems.

> The brain is a supersystem composed of numerous subsystems, every one of which is coupled to some other subsystems, but none of which is directly coupled with all the other brain subsystems. Every brain subsystem has its specific function, or peculiar activity, in addition to performing general 'household' functions. But it cannot discharge its function in a normal way without the support of a number of other systems. . . Given the postulated identity of mental function and specific brain function, the consequence of all that for psychology is obvious. The mind is neither a single homogeneous block nor a collection of independent modules à la Gall or Fodor (1983). Instead, the mind is a functional system . . . that is, a collection of distinct but interlocked brain processes. (Bunge and Ardila 1987, p.164)

Bunge and Ardila speak of the brain/mind system in general, but their vision is equally appropriate with respect to divisions of the mind, such as memory. We could readily adopt a statement such as, 'Memory is a collection of distinct but interlocked brain processes', as a credo of both cognitive and neurocognitive perspectives of the study of memory.

Remembered events and acquired knowledge

Let us contrast the multiple systems view with that of unitary memory, and do so in terms of a concrete laboratory analogue of a real-world happening.

Imagine an intelligent, healthy, highly motivated test person participating in a laboratory experiment on memory. The experimenter shows the test person a printed sentence on the computer screen that says: 'AARDVARKS EAT ANTS', perhaps in a list of other similar kinds of statements, and later tests the test person's 'memory' for the 'target' sentence, using different kinds of tests. The test person performs successfully on all the tests. (For the purpose of the exercise here we assume that one test does not change the outcome of any other.)

The question we wish to ask is this: how do we conceptualize what happened? A generalized, theoretically neutral description of what happened is this: the test person witnessed an event, that is, a particular appearance of a particular set of printed words in a particular place at a particular time. The information about the event was encoded and 'stored', and subsequently used, in conjunction with relevant retrieval information, to perform the 'memory test' given by the experimenter.

Most students of memory would accept this description of what happened and would not worry too much about the particular metaphors or the particular language used. They would probably also agree that such an initial description leads to obvious questions. Can we say anything more specific about the 'information encoded'? What is this 'information about the event'? Even a simple event, such as the appearance of a printed statement about the dietary habits of certain four-footed animals with long necks comprises many components. What was the statement (what were the words, what does each word refer to, what does the sentence mean)? What was the appearance of the statement (typefont, colours of the type, background)? Why was it presented (how does it fit into what I know about the world)? Where did it appear (what part of the world, what continent, what country, what city, what building, what room, what display device, what part of the monitor screen)?† When did it appear (how old was I at the time, what day of the week was the experiment, what list did the event appear in, how early or late in the list)? These kinds of questions can go on and on. Immediately after the occurrence of the AARDVARK event, the test person can answer all these questions, plus many more. This means that she has information available and accessible about a large number of different aspects of the event. Much of this information, presumably, is encoded and stored, making it possible for the test person to answer the same questions about the event even after a delay, relying on her secondary or long-term memory.

So far the description of the event and its ramifications are presumably non-controversial. Apart from possible squabbling about the exact terms used, it should be acceptable to most students of memory. The controversy materializes when we pose the next apparently innocent question: where is this information about the AARDVARK event stored?

Unitarians would say, 'The information was stored as a representation of the event in the memory store', or something equivalent. Again, the actual terms used are less important here than is the singular form of the noun designating the mental aftereffects of the experienced episode. It is this assumed singularity that plays a pivotal role in unitarian thinking, and that leads to the quarrel with multiple systems theorists. To understand its implications, we have to consider what happens at the time of retrieval.

Retrieval of information about the event, for the unitarians, can take many different forms, depending upon particular retrieval queries and retrieval instructions.

† The concern with the world, continent, country, and city may seem a bit far-fetched, but these aspects of one's experience are exceedingly real, even if both the test person and the experimenter are unaware of them.

Different instructions set off different processes that produce, as output from the memory store, different kinds of information about the event. The test person could consciously recollect the event of seeing the AARDVARK sentence on the monitor screen, she could recall a part of the sentence, she could recognize it as familiar, she could answer the question 'What do aardvarks eat?' (even if she did not know it before the experiment), she could include 'aardvark' as one of the responses on a test in which she was asked to name animals, she could complete the word fragment A—D-AR- with 'aardvark' (even if she could not have done it before the experiment), or she could show a galvanic skin response to the word aardvark (even in the absence of any awareness of recollection or familiarity). All of these different 'measures of memory' would reflect 'memory for' the episode of seeing the AARDVARK sentence.†

Here comes a simple test for the reader. Please read the last sentence of the previous paragraph and make sure to fully process its meaning. (If you wish, you may re-read the whole paragraph.) After you have done so, answer the question: Does that last sentence ('All of these . . .') look reasonable to you? If you respond 'yes', and especially if you think that it looks perfectly reasonable, and if you cannot imagine how anyone could find something basically wrong with the statement, then you are a unitarian. Unitarians are people who talk about retrieval of (the information about) the event or the episode. They frequently would make claims such as, 'Although effects of perceptual identification can be independent of recognition memory, performance on both types of tests can apparently rely on *memory for particular prior episodes*' (Jacoby 1984, p.149, emphasis added), or such as, 'On an indirect test . . . *memory for the target episode* is inferred from its effect on task performance (e.g., facilitated fragment completion for previously studied words)' (Toth *et al.* 1992, p.46, emphasis added). Multiple memory theorists would never say anything like it, as we will see presently.

In brief, then, unitarians postulate a single (even if complex) representation of the event, in one (large) memory system, and talk about different aspects of that representation being retrieved in different tasks, all such retrieval implying 'memory for' the event. In the unitarian approach, dissociations in performance on different tests come about because different retrieval cues, or different retrieval instructions, serve to provide access to different features of one and the same representation of the event in the memory store. Unitarians believe that even when the event cannot be retrieved explicitly, it may be quite possible to retrieve it implicitly. People with memory impairment, too, may demonstrate their 'memory for' the experienced event through enhanced performance on tasks such as lexical decision, perceptual identification, or fragment completion. Because the source of such enhanced

† The term 'memory for an event', or 'memory for' whatever, is widely used. I put it in quotation marks, because I try to avoid using it wherever possible. I think of 'memory' as a general capacity to acquire, retain, and use information, and 'memory for' an event would therefore mean 'general capacity to acquire, retain, and use information for an event'. This, of course, is not what is intended. Instead of using the colloquial expression, 'memory for an event', one could use more precise expressions, such as 'recollection of an event', 'remembering an event', or 'retrieval of information about an event', depending upon the desired intention.

performance is the original study episode (an undisputed fact, of course), some writers have even referred to the retrieval manifested in such situations as 'episodic memory' (Light and La Voie 1993, p.220), a statement totally at odds with the meaning of episodic memory in the multiple-memory theory (Wheeler *et al.* 1997).

Different memory systems

How would a multiple-memory theorist answer the question, 'Where is the information about the AARDVARK event stored?' The answer is 'It depends entirely on what aspect of the event you are talking about.' This answer means that there is no 'single' engram, or single memory trace, or single representation of the event. (By 'single' I do not mean 'localized'. A 'single' representation may be 'distributed', either abstractly or neuroanatomically, yet act as a common unit.) The perceived event is 'assembled' by many interacting brain systems, many of which are changed in the process. As a result, different kinds of information, representing the many different aspects of the event, are stored at different independent 'storage sites'. These sites correspond to memory systems and their subsystems, although different systems and subsystems also vary in ways other than just the storage sites (Schacter and Tulving 1994). There is nothing resembling a 'single representation' (single trace, single engram) of the AARDVARK event anywhere in the brain.

Different memory systems have evolved to serve special functions that cannot be readily duplicated by other systems (Sherry and Schacter 1987). For example, one of the functions of primary memory, or working memory (Baddeley 1986), is to make a neurocognitive 'sketch' of the perceived event. The properties of the sketch depend on the event, its context, the nature of attentional processing of the input, and other variables. Parts of the sketch are accessible to the rememberer in the form of immediate conscious awareness, and the information it contains can be used in ongoing mental activity. While working memory operates on the incoming information in this manner, other memory systems in the complex, massively parallel computational machine that is the brain are also involved, separately from the processes of working memory (Pashler and Carrier 1996; Shallice and Warrington 1970, Tulving and Patterson 1968). Thus PRS, the perceptual representation system (Schacter 1990; Tulving and Schacter 1990), encodes and stores information about the features of the visual objects represented by the letter strings AARDVARKS EAT ANTS. The semantic memory system, or a set of its (presumably) numerous subsystems, encodes and stores propositional information about the feeding habits of animals named aardvarks. The episodic system integrates, registers, temporally dates, and spatially localizes the rememberer's experience of the experience of being present and witnessing the sentence appearing on and disappearing from the screen.

For a multiple systems theorist there is no such thing as 'implicit retrieval' of the information about an event. Nor does any kind of implicit retrieval of information laid down at the time of the event constitute a 'memory for the event'. Information about an experienced event can be retrieved only explicitly, that is, with conscious awareness of the earlier experience. Such explicit retrieval is called 'remembering', or 'conscious recollection'. It is important to note, lest confusion reign, that what is remembered, or consciously recollected, is not the event, but the event as experienced (Perner and Ruffman 1995; Wheeler *et al.* 1997).

A person serving as a subject in an experiment in which the AARDVARKS EAT ANTS display is presented for inspection can, later on, implicitly (that is, without conscious awareness of the source of the information) retrieve (that is, make use of) other kinds of information that were encoded and stored at the time when the original event occurred. Such implicit retrieval may be manifested in perceptual priming: the subject could demonstrate enhanced ability to identify and name any of the three presented letter strings. In the multiple systems view, such enhancement would be regarded as an 'expression' of the perceptual representation system, PRS.

Implicit retrieval may also be manifested in the subject's improved ability to answer questions such as 'Can you tell me something about the feeding habits of the animal whose name appears first in the dictionary?' In the multiple systems view, such an improvement in memory performance would be regarded as an unknown mixture of expression of semantic and episodic memory. When the subject no longer remembers the experienced AARDVARK event, but still knows the answer to the question, or when the subject is amnesic and cannot consciously recollect the study episode but knows the learned fact (Hayman *et al.* 1993; Markowitsch *et al.* 1993), we can conclude that the expressed knowledge represents an output of the semantic memory system. In theory, one could expect perfectly normal perceptual or conceptual priming even if the respondent's episodic memory system were totally dysfunctional, or even if there were nothing left of the originally stored information about the event in the episodic memory system.

Thus, the multiple systems view of basic differences between the remembered experience, knowledge of a fact, and enhanced ability to identify an object, even if all of them originate in the 'same event', leads to the expectation that different areas of the brain are involved in these different achievements. We return to this issue later in the chapter.

Implicit memory versus episodic remembering

It also follows from what has been said that people who have suffered the kind of brain damage that causes amnesia do not and cannot demonstrate their 'memory for' the experienced event through enhanced performance on tasks such as lexical decision, perceptual identification, or fragment completion, because these tests do not address any questions about the remembering of the experienced event. The tests address the person's ability to perform a current task that need not, in any way, depend on information stored about the experienced event as such. Also, amnesics do not demonstrate their 'memory for' the event by being able to answer the question, 'What do aardvarks eat?' There is no reason, in the multiple systems world, why anyone, whether amnesic or not, cannot make use of information stored in semantic memory without invoking one's episodic-memory capacities (Tulving 1995).

A person's enhanced ability to name the objects that the experimenter gives them credit for, on a priming test (e.g. complete the word fragment A—D-AR- with 'aardvark') or the semantic memory test ('What do aardvarks eat?'), may have, and in experiments does have, its origin in a specific episode, but the enhancement is independent not only of the remembering of the episode, but also of the episode itself. It is independent of the *remembering of the episode*, as demonstrated by various dissociations between priming and explicit recognition (Tulving *et al.* 1982; Hayman and Tulving 1989; Nyberg and Tulving 1996). It is independent of the *episode itself* in the sense that no particular episode is necessary for the enhancement. Exactly the same effect-enhanced performance on the priming task and the semantic question-answering task could have come about as a consequence of a large variety of rather different episodes. A particular event may be sufficient to create the neural basis for an enhanced skill or added knowledge, but it is not necessary.

A stark contrast to such a state of affairs in implicit memory—a given event is sufficient but not necessary for subsequent enhancement of performance—is episodic remembering. What a person consciously recollects of the event depends very much on the event and the person's original experience of it. The appearance of the AARDVARK sentence in a particular place at a given time in a given place is absolutely necessary for the person's remembering of the experience of that particular event. There is no way that a different event could be substituted for the one actually experienced without changing the 'memory for' the event.†

In sum, then, according to multiple systems theory, there is no single representation of an originally encountered event anywhere in the brain. Different kinds of information about the event are 'stored' in different memory systems and subsystems, and used as needed. Dissociations in performance on different tests of retrieval come about because the relevant information is independently accessible from these different 'storage sites' in the brain. The kinds of information that support perceptual priming and the operations of semantic memory exist, and can be used, independently of the information that is necessary for conscious recollection of previously experienced events.

CONVERSION OF A UNITARIAN: A PERSONAL CONFESSION

I said earlier that psychological students of learning and memory who lived and worked before the 1970s were unitarians, even though they did not realize it at the

† It is well known that recollections of past events are not always veridical and that sometimes people can remember events that never happened (Roediger and McDermott 1995; Schacter *et al* 1996). Such 'false remembering' is not yet understood and is being vigorously studied. More complete understanding no doubt will come with further research. The lack of complete veridicality of remembered events, however, does not change the basic nature of episodic memory, or its differences from PRS and semantic memory.

time. I was one of them. I collected my first data in a learning experiment in 1957. If someone had asked me at that time how many different kinds of learning there were, I would not have understood the question. (The term 'memory' was still taboo at the time, and young beginners in the field did not dare to use it any more than they would dare to question what passes for political correctness in our more enlightened age.) How many different kinds of air are there? How many different kinds of water? Kinds of learning? What silly questions!

I was a unitarian, not only because I did not know any better, but also because I too had been imprinted on Occam's razor and had learned about the inestimable virtues of parsimony. Science was a search for the general principles and universal concepts governing phenomena we were interested in, and splitting up what one was going to study was obviously not the way to begin. Therefore, for me learning was learning, and memory was memory. In my zeal I wielded Occam's razor wherever and whenever I thought I saw a chance. Thus, organization was organization, information was information, items were items, cues were cues, retrieval was retrieval, and to top it all off I wrote several papers passionately defending the 'fact' that there is no difference between recall and recognition. At the time I had not yet heard of Einstein's dictum that it is the duty of scientists to simplify nature as much as possible but not more, and if I had, I might have thought that even Einstein had his limitations.

Now that I have come to my senses I am a bit embarrassed about some of the things I said and wrote in my ardour for parsimony, even if I can rationalize it by attributing it to idealistic ignorance of the youth. Besides, I am glad that I experienced the faith, because I feel that it makes me more tolerant now of the views of those who have not yet seen the light. I am even more glad that I myself was lucky enough to realize the errors of my early ways before it was too late to do anything about them. I now think of unitarianism as something like measles, or puberty: an inevitable and necessary, but relatively painless and transitory, stage in one's life that most people get over in the normal course of maturation and development.

What brought about my 'conversion'? Like all historical questions, this one too does not have an objective answer. About the best I can do is to imagine that my original faith was shaken by facts that kept piling up that were at variance with the theme of unity. In addition I can put my finger on specific instances that greatly helped me to shape my new convictions and, later, to keep them. In the last part of this chapter, which is even more personal than the rest of it, I mention four 'critical incidents', although their actual number is considerably larger.

Stochastic independence

The first incident was an experiment we did in the summer of 1980 and published two years later (Tulving *et al.* 1982). Subjects were shown long lists of individual words and later tested for (i) their ability to recognize the words (old or new?), and (ii) their ability to complete the graphemic fragment of the word (e.g. say ASSASSIN when shown the fragment A—AS—N). The words that the subjects had studied were, of course, recognized much more readily than non-studied words, and, not surprisingly, also more readily identified in the fragment completion test.

What was totally unexpected was the fact that whether or not a subject remembered having seen a particular word in the study list, as judged by the recognition test, had no bearing whatsoever on whether or not the subject could complete or not complete the fragment of the same word. The two performances were stochastically independent. The finding was unexpected and novel, because no such independence between different measures of mnemonic consequences of study of a single set of items had ever been reported before. All previous experiments, in which different measures of memory of individual items had been subjected to a contingency analysis of the sort we used, had always shown at least positive even if not perfect association between the measures (e.g. Flexser and Tulving 1978; Ogilvie *et al.* 1980; Postman *et al.* 1948; Rabinowitz *et al.* 1977, 1979; Tulving and Wiseman 1975; Wallace 1978; Watkins and Tulving 1975).

What was going on? A reasonable idea, fortified by the findings from amnesic patients (Warrington and Weiskrantz 1968, 1974) was that we had bumped into a new kind of memory, one obeying different principles than those involved in the memory supporting old/new recognition. Hence we surmised that 'priming effects in word-fragment completion may be mediated by a cognitive system other than episodic and semantic memory' (Tulving *et al.* 1982, p.336).

Man without episodic memory

A second eye-opening experience consisted in my meeting and studying a man (KC) who, as a result of traumatic brain damage that he had suffered in a motorcycle accident in 1980, has completely lost the ability to remember any personally experienced events although in most other respects he is quite normal (Tulving 1985*b*; Tulving *et al.* 1988*b*). Especially interesting to me was the fact that he had retained a great deal of the knowledge that he had acquired during the years before the critical injury. His language is intact, he can read and write and solve problems, he knows mathematics, geometry, history, and how to play chess and the organ. He knows who he is, where he lives, where he went to school, and has no difficulty locating the family summer cottage on the map of Ontario, where has spent a lot of time. He can even learn new factual information, albeit slowly, and shows more perceptual priming than an average college student (Hayman *et al.* 1993; Tulving *et al.* 1988*b*, 1991). He has good manners, has a quiet sense of humour, and never confabulates. Also important is the fact that as long as he stays inside the house, and goes for walks only in the immediate neighbourhood, which he knows, he is perfectly capable of looking after himself in every respect; he requires no supervision or caretaking of any kind.

KC accomplishes all that, and much more, without being able to consciously recollect any experience he has ever had. His anterograde amnesia, especially for autobiographical events, is as dense as that of any other amnesic ever described in the literature, including HM (Corkin 1984), although, unlike HM, he can learn, slowly and laboriously, new factual verbally expressed information (Hayman *et al.* 1993; Tulving *et al.* 1991). His retrograde amnesia for personal happenings extends back to the earliest days of his life. Regardless of how precisely or specifically he is prompted and reminded of happenings in his past, and regardless of how hard he tries, he cannot remember, that is consciously bring to mind, any events, single or repeated, from any period of his life. Cases resembling that of KC have now been described by others (Hodges and McCarthy 1993; Markowitsch *et al.* 1993; Calabrese *et al.* 1996; Van Der Linden *et al.* 1996).

The striking dissociation between KC's totally dysfunctional episodic memory and his relatively functional semantic memory, as well as his excellent perceptual priming, suggests a separation of the corresponding processes at the neural level. His case represents an extreme illustration of the conclusion arrived at in an extensive clinical neurological investigations of memory and amnesia almost half a century earlier (one that I did not know about at the time when I was spending time with KC):

> A study of pathways of memory formation has revealed a basic fact not suspected when this study began—there are two separate pathways for two kinds of memories. The one is memories of life experiences centering around the person himself and basically involving the element of time. The other is memories of intellectually acquired knowledge not experienced but learned by study and not personal. (Nielsen 1958, p.25)

Brain imaging

The third critical event supporting my growing convictions about multiple memory systems occurred in 1987 in Lund, Sweden. David Ingvar and Jarl Risberg, two well-known pioneers in the development of the technique of measuring regional cerebral blood flow (rCBF) in awake, alert people, kindly agreed to collaborate with me in doing a pilot study comparing episodic and semantic memory retrieval. In this study we measured changes in cortical blood flow that signalled changes in neural activity. During some brain scans in our study, subjects were silently reminiscing about past personal happenings; during other scans, they were thinking of the facts they knew in a given category. We found three subjects who consistently produced strikingly uniform results: episodic remembering of past events was accompanied by relatively higher levels of blood flow in anterior cortical regions, whereas retrieval of semantic knowledge was associated with relatively higher activations of posterior cortical regions (Tulving *et al.* 1988*a*; Tulving 1989).

Thus, as a result of our little study we had visible evidence that living brains distinguish between thoughts involving 'self-in-the-past' and thoughts about less personal happenings of the world. Although the finer grain of the blood flow data was uninformative, and although we could not rule out alternative interpretations, I found the data most encouraging: they fit surprisingly well into the developing pattern.

A fourth incident, or rather a series of incidents—I think of them as 'clinchers'—consisted in the confirmation, extension, and refinement of our Lund findings. In 1993 we gained access to the newly established positron emission tomography (PET) facility at the Clarke Institute of Psychiatry at the University of Toronto, and could begin serious brain imaging studies of episodic and semantic memory. The results of the Toronto studies (Kapur *et al.* 1994; Moscovitch *et al.* 1995; Nyberg *et al.* 1996*b*, 1997; Tulving *et al.* 1994) as well as those reported by other laboratories (Andreasen *et al.* 1995; Fletcher *et al.* 1995*a*,*b*; Shallice *et al.* 1994) showed striking differences in the neuroanatomical sites that are involved in episodic and semantic retrieval. One of the most consistent findings is that retrieval of semantic (general knowledge) information engages left prefrontal cortex more than right prefrontal cortex, whereas retrieval of episodic information engages right prefrontal cortex more than the left. This pattern of brain activation, labelled hemispheric encoding/retrieval asymmetry, or HERA, was unexpected in terms of existing knowledge, but it has turned out to be remarkably robust (Buckner 1996; Haxby *et al.* 1996; Cabeza and Nyberg 1997; Nyberg *et al.* 1996*a*, 1997). Other regions of the brain have been identified that show differential activation in episodic versus semantic retrieval (Buckner and Tulving 1995; Shallice *et al.* 1994; Fletcher *et al.* 1995*a*,*b*; Cabeza and Nyberg 1997), and more will undoubtedly be found in the future. But the data already available have added powerful support to the biological reality of separate memory systems.

With these kinds of experiences, it is easy, and fun, to be converted, even if it means that I have ambivalent feelings about the non-believers. Those students of memory who have not met people such as KC, and who have not done any PET or fMRI studies of memory, and who therefore can afford to think that 'perhaps there is something wrong there, somehow', may get away with thinking unitarian thoughts, but I suspect that it will not be for long. The whole *Zeitgeist* in our field is changing, rapidly.

CONCLUSION

The title of this chapter is 'Study of memory: processes and systems'. The crucial word in it is 'and'. Both processes and systems constitute the warp and the woof of the fabric of memory: we cannot have one without the other any more than we can have continents without oceans or heredity without environment. One can, and people usually do, approach the study of memory either from a cognitive (process oriented) or a neurocognitive (systems oriented) perspective, but on logical and rational grounds there is no conflict between them. The two approaches are complementary, and both are necessary for a fuller understanding of memory. Because all memory systems operate in terms of processes—some shared with other systems, some unique—the issue of processes versus systems is a non-issue. There can be no conflict between process and systems orientations, and no controversy.

There still exists what appears to be a real disagreement today between those who believe in a single system and those who believe in multiple systems. This disagreement, however, is more a tiff than a serious rift. Moreover, there is every reason to believe that the tiff is a passing phenomenon that will soon be behind us. The weight of evidence is relentlessly shifting in favour of multiple memory systems, and there is no sign that the trend is going to stop or to reverse. This is why the future will belong to the idea of multiple memory systems.

Because the eventual general acceptance of multiple memory views is no longer in doubt, it would be appropriate to invite all cognitive theorists to renounce their unitarian faith and to join the effort to contribute constructively to the solving of the many daunting problems that lie on our way to a fuller understanding of memory with its multiple processes and multiple systems!

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Memory: Systems, Process, or Function?

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