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Implicit and Explicit Representations of Time

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INTRODUCTION

During most of the first century of its existence as a more or less distinct subject within the domain of experimental psychology, the study of time has manifestly been a *psychophysics of duration*. To a large extent experimenters have dealt with the curious fact that time will now seem to fly and then again appear to drag intolerably. In literature as well as in personal, everyday experience this is perhaps the most remarkable feature of our experience of a changing world. Absolute thresholds (the minimum amount of time that we perceive as an enduring moment) and relative thresholds have been determined as a function of all sorts of physical, physiological, and cognitive variables. In these experiments intervals are compared, produced, reproduced, or estimated (e.g., Gibbon & Allan, 1984; Macar, 1985).

Methodologically and conceptually, the psychophysics of time has been consistent with the behaviorist tradition in experimental psychology. Models have usually been of the "clock-and-regulator" type. This implies that, whatever variable is studied for its effect on the subjective rate of flow, it is considered to affect the rate of an internal clock which, as a result, will slow down or speed up, thus creating the subjective feeling of time dragging or accelerating (Treisman, 1963). Irrespective of the details of the numerous models in this tradition, they all rely strongly on a clock metaphor and as such they may in fact be reduced to simple variations on the theme of *time measurement* or *chronometry* (e.g., Fraser, 1982).

With the arrival of cognitive psychology, this reductionist approach to the experience of time has changed. In recent years the temporal aspects of cognition and the cognitive aspects of temporality have begun to converge, on their way to become an integrated, fairly substantial topic within the domain of general experimental psychology. Time psychologists have become concerned with the syntactic (rhythmic) and semantic (conceptual) properties of time, the planning of future action, the temporal structure of speech and language, event perception and the narrative structure of event sequences, episodic and autobiographical memory, the subjective value of time, and several other topics. In particular, the relation between time experience and memory organization has come under close scrutiny.

From the cognitive point of view the experience of time is not primarily the perception or retention of duration. On the contrary, duration is in fact a rather abstract outcome, a derived and highly formal product of the mind. Even in its nonverbal disguises, experimentally dressed as the comparison between intervals or the reproduction of a preceding interval, the influence of a highly public and language-dominated convention is clearly at work.

If I claim that duration is a product of the mind, the question is what it is derived from, or at least what the function is of this apparently extremely well-developed and well-maintained abstraction. My answer, as it emerges from this chapter, is that the experience of time is the conscious product of processes that enable us to cope with the sequential contingencies of reality. And duration is only one abstract aspect of this product. Memory is the ensemble of the processes that temporally organize our experiences. This view of memory as process or strategy deviates from some conventional views that treat memory as a reservoir of facts and rules. The reasons become clear in the course of my argument, but the view presented here is consistent with that of at least a number of other authors. Schank (1986), for instance, pointed out that "the test of an effective understanding system . . . is not the realism of the output it produces . . . but rather the validity of the method by which that output is produced" (p. 11).

In summary then, time is not just duration; it is not even duration in the first place. Time is more, and the question remains what it has been for more than 15 centuries: "*Quid enim est tempus?*"- What then is time?

THE DUAL NATURE OF TIME EXPERIENCE

With the arrival of cognitive psychology it has become acceptable again to talk about intentionality. Brentano's century-old claim that the fundamental property of mental processes is that they are always *about* or directed *at* something is once more taken seriously. Certain topics that were once prominent in phenomenological psychology as it was propagated especially by Brentano, Husserl, and Merleau-Ponty are once more attracting attention (see e.g., Brockelman, 1985; Miller, 1984; Sherover, 1975). The experience of time is such a topic. Time has, right from the beginning, occupied a very central position in phenomenological psychology. Both Brentano and Husserl considered it one of the fundamental "constituent" factors of experience.¹

Phenomenological analysis has, in particular, highlighted the dual nature of time in human behavior. This duality finds expression in *action* and *reflection*, respectively.

In the phenomenological view the first temporal mode is an implicit, direct tuning of human action to the dynamics of the surrounding world. Action, our concrete, intentional behaving in a given situation, takes place in an immediate action field (called the *Now* or, with a German term, the *Präsenzfeld*) in which retentions of earlier experiences and anticipations about the future are implied. The temporal structure or *temporality* of behavior, that is, their dynamics, their timing, their tuning

¹ I wish to emphasize that the phenomenology of time in its present interpretation is not in terms of the idealistic, philosophical form it takes in Husserl's later work, and most certainly do not take the form in the psychologically meaningless, metaphysical obfuscations of Heidegger.

to the objects and events that they are *about* (the so-called *intentional objects*), is not normally accessible to introspection. The temporality of our behavior is, in other words, cognitively impenetrable. An action *expresses* time but is not defined by any representation, that is, by temporal relations in terms of duration, order, date, and so forth, in a person's consciousness. This form of temporality builds on what Schacter (1987) called *implicit memory*. It is the form of memory which expresses itself in and through our knowledge or performance but that cannot be represented in propositional (verbal) terms (see e.g., Richardson-Klavehn & Bjork, 1988).

In contrast, the second temporal mode distinguished in phenomenological analysis deals with time viewed as past, future, order, or duration. It is the conceptual structure by means of which humans express their awareness of temporal relations between events and their reflections on their action. Reflection makes the action that is the object of reflection into an intentional object, and the *implicit* Now in which that action is taking place thereby becomes an *explicit* temporal object, an event that lasts so long and that can be placed at such a place in an explicit temporal dimension past-present-future, that is, in a historical context: "To be self-conscious means to be aware of oneself as a temporal relation (...) as a set of narratively shaped active temporal relations in the progressive tense" (Brockelman, 1985, p. 76). Past experiences are localized at a point in the remembered past, expectancies are projected as events that are still to happen in a future that gradually comes closer and closer. Conscious reflection being cognitively penetrable, it enables the organism to plan its actions and to adaptively tune to the prevailing circumstances in the world.

TIME IN COGNITIVE PSYCHOLOGY

The question considered next is what psychological views of time look like if they are considered to be a regular subject within the domain of cognitive psychology. In order to answer this question I choose a definition for *time* that I have been using for some years and with a great deal of satisfaction: "Time is the conscious experiential product of the processes that allow the (human) organism to adaptively organize itself so that its behavior remains tuned to the sequential (i.e., order) relations in its environment" (Michon, 1985, p. 20). The merit of this definition is that time is defined, not as a thing with attributes or a property of the existential mode of things, but as a process or ensemble of processes that is capable of generating the entire conceptual structure that we conventionally call time.

This definition is consistent with the dual character of the cognitive architecture that I discussed earlier in this chapter. In the first place, it claims that there are processes that allow us to tune to the course of events in the external world or that, with another phrase, allow us to maintain a dynamic, interactive relation with our environment of a kind that the innocent bystander would qualify as "smooth" or "effortless." An important implication is, moreover, that time as such plays no role in these tuning processes. Whether or not the duration of a movement is long or short is not dependent on a direct manipulation of the duration parameter, but of other dynamic parameters, such as force, or momentum. The definition also implies that time is the consciously experienced product of this tuning process. That is, we must look for a process or ensemble of processes that can explain (or reproduce) the entire spectrum of conscious temporal experiences.

THE HUM IN THE BASEMENT

The philosopher Lawrence (1986) has compared the implicit temporality of automatic, unattended behavior with "the hum in the basement," with the noises your central heating or your washer are making but that you will not notice until one day they stop inadvertently. Such behavior can express highly complex temporal relations, but one will not find time as an explicit control parameter in the control structure. The quality (smoothness, precision) of an automatic action relies on other factors. This fact is, physically speaking, fairly trivial but psychologically speaking it is not: after all it is conceivable that duration as such might have a causal influence, even in the case of automatic behavior, if only pure duration would be explicitly represented in a neural code. There is, however, little evidence for such an encoding, except for the various biological rhythms that, however, have comparatively long periods (month, day, 90 minutes).

Thomassen and Teulings (1985; also Teulings, 1988) have shown that relevant control parameters of handwriting are the force exerted and the kinematic properties of the hand-arm system, but not duration as such. Systematic variations in the conditions under which the writing was produced clearly revealed influences from the former parameters on letter forms, whereas there was no such systematic effect on the duration parameter as such (see also Jones & Boltz, 1989; Shaffer, 1985). Time is a product, not a building brick, of behavior.

A second line of research is concerned with the question of whether time is an automatic byproduct of other information processing activities. This research (e.g., Jackson, 1986; Michon & Jackson, 1984) has shown that such temporal information is not encoded unless it is explicitly attended to. The conclusion is that time (in the sense of duration, epoch, etc.) is not only not represented explicitly in automatic behavior, but in addition that we are not capable of forcing someone to construct such a representation, even if we explicitly try to induce it by inputting exact temporal information: explicit training of the duration of muscle twitches is not likely to improve one's chance of winning an Olympic gold medal.

Visual perception proceeds in a highly parallel and automatized fashion. One may therefore expect that in this domain there will be no explicit representation of time. J. J. Gibson (1969, 1975) has pointed this out very explicitly. He has repeatedly emphasized that time is not a perceptual dimension, but a construction *a posteriori*, based on the dynamic structure of the perceptual field. Again, this supports my thesis that time in conscious experience is a derived entity. Because psychology is still very much dominated by Kant's transcendental view of time and space, this claim may still seem revolutionary. It is, however, at least a century old. As early as 1885 the French philosopher Guyau made the point in great detail and very eloquently (Michon, Pouthas, & Jackson, 1988).

Although there is a considerable body of research into the perception of "natural" movement—e.g., recognizing the gait of people moving about "anonymously" and the encoding of abstract movement patterns,—there is no research on record to find out if time (duration) as such plays a role in the identification and retention of such patterns of action. The ease with which people can understand and retain even very disorderly cinematographic information adds to the plausibility that duration as such is either not coded at all, or else is coded only very indirectly and incompletely.

THE CONCEPTUALIZATION OF TIME

The experience of time—that is, the perception, meaning, and use of time as duration, past, now, future, and so on—is inextricably associated with conscious information processing, with the reflective mode of thinking, or with whatever other name this relation may have received in the literature. Temporal cognition belongs to the declarative domain of knowledge. The representation of temporal relations, therefore, is a form of high-level cognition and should be accessible to the same sort of empirical methods that apply to problem solving, decision making, comprehension, or explanation. In this light, a relevant question is why explicit representations of time are, in fact, at all necessary. A first good reason is an impasse in the process of action tuning. A person may for instance be in a situation for which he or she has no appropriate automatic behavioral procedures available. The second reason is one of communication. In order to understand each other, people must be able to give orderly and ordered accounts of their behavior. Such is the structure of narrative.²

In this context, time is conceived as a conceptual structure—a mental model in the sense of Johnson-Laird (1983)—a structure that is designed specifically to represent and solve problems that emerge whenever the tuning process fails for some reason or other. An example of this function of mental models is the temporal organization required to repair a vacuum cleaner. Unless one already happens to be an experienced vacuum cleaner mechanic, one is helped a great deal by treating the disassembling task as a temporal problem and by relying on an order scenario. The many parts are to be located on the workbench in the order in which they were removed, and successful reassembling mostly depends on following the proper reverse of this order, because the other important question of where and how the part is to be re-installed can frequently be answered by considering the shape of the various units. A nut simply "asks" to be mounted on a bolt.

Time as a conceptual structure can take three forms—literal or verisimilar, metaphorical, and formal—that are functionally more or less equivalent. In each case we are dealing with a temporal schema enabling us to specify sequences of events for later reconstruction, or for anticipating future events. The difference seems to reside mostly in the level of abstraction that is required to match a representation with the temporal structure of the concrete episode that it represents.

THE VERISIMILAR REPRESENTATION OF TIME: BEING REMINDED

Many situations in which humans must, in one way or another, represent temporal relations explicitly are extremely trivial—much more trivial, in any case, than the maintenance of a vacuum cleaner. Generally speaking, information processing in these circumstances might be automatic, but frequently the actor is asked for an explanation or a suggestion. Take, for instance, the question, "How far is it to the post office?" The answer may well be stated as "About 20 minutes if you keep walking like this" or "Maybe 10 minutes if you are in a good condition." The informer must have a

² It might be added, however, that people seem capable of learning to deal with highly complicated temporal relations in narrative with surprising ease.

representation of spatial distances and must also be able to superimpose on this representation a time scale that can be calibrated on the basis of relevant external information, in this case the observed or inferred walking pace of the inquirer.³

Humans normally have access to a large repertoire of temporal standards for concrete, everyday, "natural" events, associated with scenarios (scripts, frames), not only in order to efficiently execute routine activities, but also in order to explain and communicate. Classic temporal phenomena like the acceleration and deceleration of the subjective flow of time can actually be explained more appropriately in terms of deviations from the expectations raised by a scenario one is reminded of (e.g., Jones 1976, 1985; Jones & Boltz, 1989 ; Michon, 1967, 1985; Shepard, 1984) than in terms of internal counters, clocks, or memory registers that allow estimates of passed or passing duration in terms of the *number* or *complexity* of events that take place during an interval. Jones and Boltz (1989), for instance, demonstrated this by comparing judgments of the durations of "natural" melodies with those of structurally malformed melodies. The latter induce grossly inadequate expectations in the subject about their endpoint. As a result, the subject may experience and judge the malformed melody as being either shorter or longer than a corresponding "natural" melody.

We do not yet know in sufficient detail how temporal relations are represented in these concrete scenarios. Shepard (1984) has, in a long series of experiments, studied the manipulation of mental images of two- and three-dimensional objects. The time it takes to execute such a mental manipulation—the rotation of a three-dimensional block shape, for instance—is found to be proportional to the extent and complexity of the movement in mental space. But this finding in itself does not tell us very much about the explicit representation of the temporal relations involved in such manipulations. Shepard remained silent on the physical properties, or rather the represented physical properties, of his mental objects. Do his mental shapes have mass or density? There should be differences between the properties of an image of a cube made of mental styrofoam and one made of cast mental iron—or is it mental cast iron? The important questions are to what extent mental models of real processes are in fact dynamic models, and to what extent the properties of these models are coherent and consistent with, say, Newtonian mechanics. This question has come under scrutiny only in recent years.

The burgeoning field of qualitative or naive physics deals with precisely these questions (e.g., DiSessa, 1983; Freyd, 1987; Hobbs & Moore, 1985). Findings from this research seem to point out that representations of a fair number of elementary physical processes—such as magnetic attraction, free fall, friction, or collision— may indeed be fairly consistent across subjects and that, moreover, they tend to be more consistent with an Aristotelian worldview than with the views of Newton, let alone Einstein. Although Newton has taught us, for instance, that a stone, when thrown, will no longer be subject to the force of the throw, we still seem to believe with Aristotle that the force of the throw—its *impetus*—will "go with the stone" and only gradually fade, causing the stone to slow down.

Despite this increased attention, cognitive psychologists have not yet answered the question of whether or not the representation of temporal relations in the mental world is consistent with the physical laws that appear to hold in this world. Apart from

³ There may be considerable cultural differences at play in this case. In large parts of Europe my description stands, but elsewhere (*viz.* the USA) it may not.

Piaget (1946), Mashhour (1964) and Montangero (1977, 1985) the verisimilar representation of time in basic scenarios of real-time events has not yet been studied in any detail. The latter authors have all dealt with the question of whether or not the basic kinematic relation *distance* equals *velocity* x *time* holds subjectively. Piaget did show that this is the case only in the advanced stages of human development. Montangero, working in the tradition of Piaget, did confirm this, but he went much farther. He presented considerable evidence for a triadic conceptualization of time: time in relation to distance and velocity; time in relation to frequency and number; and time in relation to states and transitions between states. At the earlier stages of development humans deal with time in each of these representational domains independently (and initially incoherently). Only later do the separate triads merge into a single consistent model with one concept of time. This supports the century-old view, phrased in a most interesting cognitivistic way by the French philosopher Guyau (1890/1988) that establishment of a consistent representation of time is a matter of strenuous cognitive effort.⁴

Mashhour (1964) made an attempt to show that Stevens' power law holds not only for distance, velocity, and duration separately, but that there is even a power relation that holds between these three variables. In other words, qualitative kinematics is apparently consistent with a relation of the form:

$$(\text{distance})^\alpha = (\text{velocity})^\beta \cdot (\text{time})^\gamma$$

Within certain constraints Mashhour did indeed find fairly stable values for α , β and γ within subjects, suggesting that numerical estimates of the duration of simple events are consistent with the qualitative physics that an individual subject happens to entertain.

The verisimilar representation of time is not restricted to the microlevel of events. Schank (1982, 1986), among others, has proposed, with great force of arguments, that human behavior in everyday life is steered by scenarios, explicit representations of remembered situations that are sufficiently close to the prevailing circumstances to serve as a guide for further action. This approach to dynamic memory reiterates and develops Guyau's view that memory is simply the way of effectively and efficiently using the strategies by which we organize our knowledge representations (Guyau, 1890/1988). Guyau's theory of dynamic memory is beautifully reflected in Schank's theory; but, unlike Schank, Guyau focused directly on the fundamental significance of the representation of time as a cognitive strategy.

An Illustration: Political Timing

Schank's position implies that the "best brains connect everything with everything else and so are constantly reminded" (Schank, personal communication, 1987). To be flooded with reminiscences is, however, a mixed blessing. Luria (1968), in his penetrating analysis of the mind of a mnemonist relates various examples of his subject "S." being overwhelmed by memories and images upon reading even a simple

⁴ See Michon, Pouthas, and Jackson (1988) for a translation of Guyau's original text and an extensive discussion of Guyau's views on the origin of the idea of time.

poem. More specifically, as many authors have pointed out, the correspondence between the episode one is reminded of and the present situation may indeed be coincidental and thus provide the wrong guideline for action that no "tweaking" can redress. Reason and Embrey (1985) emphasized this in the context of the likelihood of major catastrophes. Neustadt and May (1986) did pretty much the same in their analysis of major political disasters, one of which was the Vietnam adventure of the United States. To prevent such disasters, or at least to reduce their likelihood, Neustadt and May suggested that every plausible scenario for action be subjected to a very careful time-path analysis. What they mean by this can be illustrated by the following example.

When, in 1964, President, Lyndon B. Johnson was facing the decision of whether to make a military commitment in Vietnam, almost everybody involved was reminded of the unsuccessful French campaign in the early 1950s. On the basis of this analogy Johnson decided to actively support the basically weak and instable government of South Vietnam. In the process of deliberation preceding this unfortunate decision no attempt was made to see whether or not the temporal relations between the key events in both episodes (the French example and the expected development of the actual situation) did indeed match to a sufficient degree. The Americans thought they could draw a parallel with the final years of the French campaign. Accordingly, they felt they would be able to avoid the mistakes the French had made at that time. In hindsight, however, it turned out that the actual situation in Vietnam developed along the line that had characterized the early years of the French campaign in Indo-China. The false parallel suggested that it would be possible to eliminate the Viet-Cong with a limited commitment. The correct parallel would have pointed to the fact that the United States, with an extremely weak and corrupt ally, would be defeated in a guerrilla war against a determined enemy that could rely on a massive support from an equally determined North Vietnam.⁵

THE FIGURATIVE REPRESENTATION OF TIME: METAPHORS

Attempts at activating a verisimilar scenario from one that would be able to derive an appropriate representation of temporal relations may fail. Frequently it is impossible to be reminded of such a scenario because no comparable events have been experienced in the past. Sometimes reminding is unsuccessful because the objects and relations that need to be represented lack a concrete, perceptual basis. In these cases memory search must be extended so as to include analogies (metaphors) that allow at least a number of relevant properties and relations to be represented coherently by means of a conceptual structure that is borrowed from another semantic domain. The term *metaphor* actually refers only to the verbal expression of such an analogy, but is frequently used instead of the term *analogy*.

Carbonell (1982) described in detail the process by which an analogy or metaphor is selected and adapted as a substitute for a verisimilar scenario. If someone is confronted with events for which he or she has no appropriate verisimilar scenario, the constraints on memory search will be relaxed. The requirements for a sufficient match

⁵ There is in such cases always a Cassandra, someone destined to see more clearly but to be overruled. In the present case this role was played by the Under Secretary of State, George Ball. For the details see Neustadt and May (1986).

between the analogy and the actual situation depend on the purpose for which the analogy (metaphor) is activated. This means that an acceptable analogy must at least be capable of representing the goal structure and the strategies for action. If we wish, for example, to adopt the analogy "time is our enemy," then it must, in the first place, mean something to make war against and to defeat time (e.g., Rifkin, 1987) and, in the second place it must be possible to give meaning and content to such strategies as attacking, ambushing, or killing time. Other implied characteristics, however, such as functional relations (e.g., between regiments and platoons), physical attributes (e.g., the metallurgical composition of a bullet) need not be taken into consideration. When an effective analogy is established, the next step in the process of fitting it to the prevailing situation is to determine its extended reading—that is, its useful range of application in the target domain.

There is an abundance of temporal metaphors. *Bartlett's Familiar Quotations* (Bartlett, 1980), for instance, gives more than 600 remarkable statements about time—not counting the many related quotations about hours, years, clocks, &c. From this set I have been able to distill some 40 essentially different metaphors: time as destroyer or as healer, time as receding or approaching, time as flying or dragging, time as substance or container, and so on. Time, it appears from this list, is *absolutely relative*. For every conceptualization there is also its opposite.

The 40-odd characteristic metaphors for time can be classified quite easily in terms of a very limited set of core metaphors. Lakoff and Johnson (1980), in their discussion of the metaphors we live by, distinguished between simple metaphors that establish an orientation, an ontological categorization, or a personification of a single concept or event, and the more complex structural (or generative) metaphors that entail a whole network of properties, relations, and implications.

Of the last category, spatial metaphors are nearly always dominant. This again was pointed out already by Guyau (1890/1988), who explained the fact in an evolutionary framework. He argued that the development of the idea of time derives from the child's reaching out in space to what it has not yet, from the *distance* between "the goblet and the lips" (o.c., p. 34). Because of this spatial origin, later conceptual representations of time are likely to refer more or less naturally back to the spatial domain. Guyau's argument has been reinforced in recent times by several authors, for instance by Clark (1973) who, in an analysis of time in the language of the child, found evidence for "a thoroughly systematic spatial metaphor, suggesting a complete cognitive system" (o.c., p. 62). Gruber (1976) made an attempt to formalize this observation in his so-called *thematic relation hypothesis*. He maintained that there is a forced preference for spatial analogies in many (if not all) semantic domains, with precise (and perhaps innate) substitution rules that prescribe which attributes and relations of the target domain are mapped onto the spatial domain (see Jackendoff, 1983, for a detailed discussion). In this context I should not fail to mention the emphasis that is currently being placed on the role of visual imagery (physical *envisionment*, or *Anschaulichkeit* in German) in scientific discovery and the understanding of complex formal relations. Studies by, among others, Holland, Holyoak, Nisbett, and Thagard (1986); Miller (1986); Langley, Simon, Bradshaw, and Zytkow (1987); Larkin and Simon (1987), all seem to support the contention that one picture tells us more than ten thousand words.

An Illustration: The Bureaucracy of Time

Mixed metaphors (or mixed analogies) are sometimes extra powerful. Whereas space and, by implication, spatial analogies are inherently inert or passive, an active secondary metaphor may easily "stimulate" a static spatial metaphor. The *colonization* of time, for instance, turns out to be an enterprising, if not aggressive, extension of the spatial metaphor. It has found serious application in the domain of space-time geography and transportation (Burns, 1979), and is also frequently used or implied in sociological analyses of modern cultural phenomena (Nowotny, 1989). Refrigerators, automatic dishwashers, and day-care centers are recognized as the advanced weaponry of the colonists (Burns, 1979, p. 107).

A successful metaphor will affect the cognitive style and the activity patterns of a society. The metaphor "Time is money" for instance, can be taken to be the most "western" of all metaphors of time. It suggests that it is possible to treat time as a valuable, scarce commodity. "Time is money" not only generates a tremendous array of applicable expressions for temporal relations, but it induces patterns of behavior that are unknown or that are looked upon with contempt or puzzlement in the so-called "mañana cultures." An extravagant time management is one of the potentially harmful consequences of applying this structural metaphor.

Time management may indeed deteriorate into a pathological ritual. Around his twentieth birthday, a rather important Dutch novelist and literary critic Lodewijk van Deyssel (1864-1952) decided, as he wrote at the time, "to impose on myself an iron temporal discipline and to document in minute detail all the mechanical aspects of my intellectual functioning; one and the other with the aim of collecting the building bricks for a science concerning the properties and functioning of my brain."⁶ This mental bureaucracy which, incidentally, on occasion affected Van Deyssel's creativity, allowed him, on the other hand, to retain the extreme equanimity that he felt he needed. "Like the workings of my body . . . the temporal performance in the course of the days of my life may be investigated, in order to achieve as much as possible, an uninterrupted and desired state of mind . . . I now feel in this paper life-administration not more and not less than a (relative) omnipotence." The rituals that enabled Van Deyssel to live a totally regulated life were supported by printed routine orders, memoranda tacked to the bedposts, and alarm clocks. And yet Van Deyssel's rules and regulations did not always work. Thus, in spite of eight impressive precautions implemented on the previous night, he succeeded in oversleeping on June 29th, 1891—"among other things," he wrote, "Because my spouse has neither awakened me, nor told me to rise."

Now, a century later, time management has become a flourishing branch of industry. Time management is *big business*. Time not only must be divided, it must also be conquered, invested, shared, saved, and accounted for. Some people own a whole library of do-it-yourself books on the subject. All these books contain extensive discussions, exercises and advice about how to manage the days and parts of days and parts of parts of days, and in particular—and that is where the pathology creeps in again—about the records one should keep for later evaluation. If you want to invest your time in this kind of activity you can procure a pound-heavy time-management agenda with dozens of different types of sheets and tables. Here we see is the ultimate

⁶ The details and the quotations from Van Deyssel's unpublished diaries were taken from an article by H.G.M. Prick in the periodical *Hollands Diep* (28 February 1976; vol. 1, no. 5).

reductio ad absurdum of the temporal organization of behavior: the malignant growth of a metaphor, and the bureaucratic substitute for a personal history, a genuine diary.

THE FORMAL REPRESENTATION OF TIME: RECEIVED VIEWS

The philosopher Goodman (1984) summarized the problem of establishing an appropriate representation of the world around us as follows: "[W]e make visions, and true visions make worlds" (p. 34). In other words, of all our attempts to construct representations of reality only a few are strong enough to support a view of the world. The same is true of some representations of time that have proved so successful that we have become convinced that they simply must be telling us something essential about the temporal structure of nature. This conviction has made it possible to develop conceptual structures that are so coherent and consistent that we may call them *theories of time*.

The most conspicuous example would seem to be the clock metaphor, derived from early ideas about the harmony of spheres and the polyphonic chanting in the church. Szamosi (1986) pointed out that in particular this latter activity represents an artistic and chronometric achievement of the first order—the mastery of time in the range of actual behavior—but that as an achievement it is based on no less than 5 centuries of intense experimentation and practice.

The clock metaphor, ultimately formalized in the 17th century in Newton's mechanics, is particularly visible in theories that deal with periodic phenomena such as pendulums or waves, and in related mathematical methods such as Fourier analysis. Early in the 20th century the classical clock metaphor has disappeared somewhat behind a truly spatial theory of time. That was when Einstein, Poincaré, and Weyl introduced time as an integral part of the relativistic spacetime in which time, distance, and motion are integrated by means of a fundamental invariant, the (finite) speed of light.

Both the clock metaphor and this spatial conception of time deny the ultimate reality of time. Classical physics has for centuries attempted to rid itself of time, and relativistic spacetime physics is no different in this aim (Park, 1985). But these attempts have been less than totally successful in this respect. They have been based on the assumption that time is in principle symmetric, that is, reversible. There are natural phenomena, however, that seem to fundamentally contradict this assumption. All metaphors that represent time as the destroyer, the healer of all wounds, the teacher, or the river Lethe, give expression to the archetypal insight that what is done is done. The crystallization of this insight was achieved with the formulation of thermodynamics in the middle of the 19th century. Since then, several other "arrows of time" have been defined (e.g., Horwich, 1987; Morris, 1985). Despite attempts to explain these asymmetries away, some arrows have proved to be very resistant, and some have even attained the status of axiomatic theory (e.g., Prigogine, 1980; Rosen, 1985).

An Illustration: The Geological Time Scale

Although formal representations of time do not always require five centuries to develop as in the case of musical chronometry, their construction nevertheless requires a substantial period of time. Geology, for instance, undoubtedly one of the sciences of time, has struggled at least a century and a half with its image of "deep time," that is the relation between the structure and localization of strata and their age.

Recently, Gould (1987) has given a lively account of this struggle. In a book that explains the roles of "time's arrow and time's cycle" in the establishment of a received view of geological time he offered an analysis of the respective roles that have been played by two fundamental and quite popular metaphors of time—the pointed arrow and the circle—in the development of scientific geology during the 18th and 19th centuries. The founding fathers of geology were in fact facing two major conceptual problems. First they had to free themselves from the totally inappropriate time scale of the biblical Book of Genesis: by the middle of the 18th century evidence had accumulated that required a conceptual extension of the age of the world from several thousands to several millions, and perhaps even hundreds or thousands of millions of years. Second, they had to come to grips with an apparent conflict between the evident changes in the morphology of the earth and its inhabitants—both a sign of time's arrow—on the one hand, and the physically inspired wish to formulate general, uniform, and constant laws and processes of nature on the other hand.

It is easy to appreciate the importance of the latter point. If the physical laws that govern sedimentation and mountain formation, or the origin and extinction of live species do not remain constant over time, then every attempt at describing the history of the planet Earth and of life on Earth is basically futile and every bit as arbitrary as the time scale of Genesis. The solution that the early geologists initially saw for this dilemma was to assume that the observed changes were essentially cyclical. Thus, a change in one direction would eventually be "compensated" by a change in the opposite direction. Periods of mountain formation and erosion would eternally alternate "with no vestige of a beginning, no prospect of an end" as one of them wrote in 1788 (James Hutton, cited by Gould, 1987, p. 79).

This discussion about arrows and cycles in geology has not survived the 20th century's taste for dialectic synthesis, but traces can still be found in the distinction that biologists and paleontologists make between analogy and homology. *Analogy* is evidence for the fact that nature will occasionally repeat itself—as it did, for instance with the torpedo-shaped bodies of aquatic animals—for the simple reason, that good designs are scarce in this universe. *Homology*, on the other hand, "represents similarity through inheritance and [thereby] determines a historical time" (Gould, 1987, p. 197-198).

THE FORMALIZATION OF ACTION PLANNING: A UNIFICATION

Attempts, in the 1960s, to develop temporal logics that allow us to determine the truth value of propositions about complex relations between points in time, the so-called *instant logic*, have met with considerable success. Then in the course of the 1970s the so called *interval logic* was added to the repertoire, allowing similar exercises with propositions about the relations between (finite) time intervals (e.g., Van Benthem, 1983). From then on developments have been impressive.

There is an eminently practical reason for this acceleration that derives from the fact that temporal logic constitutes a formalization of the ways people seem to deal with their verisimilar and figurative representations of time. Temporal logics—there are several of them—may be considered as computational theories for describing complex temporal relations and for action planning (see e.g., Georgeff & Lansky, 1987). Until recently, artificial intelligence had few ways of dealing with temporal relations between events. For many applications the absence of algorithms for string manipulation is no serious matter. In the game of chess for instance there are strings of moves and positions, but the world changes only during and as a result of a particular move. Beyond that the world is frozen. Compare this, however, with an automobile approaching an intersection. While this happens the driver looks at the road in front of him and observes a car is approaching from the left. In order to cross in front of this second car the driver decides to accelerate, but just then a child dashes out. In this case string manipulation to compute the consequences of different serial actions and their outcomes is required (Aasman, 1988; Michon, 1988). Recently, several methods have been developed for the dynamic planning of action, most of which use the results of one or the other temporal logic.

Consider a robot charged with the task of storing, transporting, and delivering goods inside a warehouse. If this robot decides it must take Box A, which is located under Box B on Shelf C in Room D, and bring it to Room E to put it in Corner G before Event H takes place in Room D, then this simple chain of actions is fundamentally affected by anything that happens in the mean time, while the robot is at its job. Anything that happens to any object in this world that is not a direct consequence of an action of the robot will affect the truth and falsity of a great many propositions about this world. The maintenance of truth in the representation the robot has of its world is a computationally explosive problem and the robot will soon find itself left "buried in thought." This would happen because, at least initially, models of action planning were based on straightforward and exhaustive algorithms for updating the truth values of propositions—all propositions—about the world. But stagnation in the execution of actions is likely to occur even if certain logical or physical restrictions apply, such as the insight that an object cannot be in two different places at the same time or that a door must be open if one wishes to proceed from one room to the next.⁷ The question is how the robot can constrain its problem space sufficiently to avoid the dreaded computational explosion and at the same time remain capable of dynamically adapting to environmental change. This seems to me one of the most fundamental problems that any plausible theory of intelligence that incorporates temporal phenomena will have to solve. Although this problem has been known in various disguises for many centuries, dating back at least to Zeno of Elea (e.g., Grünbaum, 1968), it has recently attracted much attention in its formulation as the *frame problem* standpoint of artificial intelligence. (McCarthy & Hayes, 1969; Pylyshyn, 1988). More recent models for temporal planning try to avoid the frame and truth maintenance problems altogether. They do not proceed from separate frames or actions with their

⁷ The truth maintenance problem is similar to the many-body problem in mechanics. The effect of A on B and that of A on C will affect the interaction between B and C. Consequently the combined effects of B and C on A will be affected, so that the effect of A of on B and on C will change as well, and so the computation "explodes."

conditions and results, but from string of elements, *chronicles*, that represent an action sequence or episodic progression from its inception to the present instant (e.g., Lansky, 1987). Planning implies the choice of one of (perhaps infinitely) many possible worlds that are consistent with the course of events up to the present point in time, and that in addition meet the action constraints imposed by the present circumstances. This approach avoids the problem of dealing with the world as a succession of inert states that requires an explosive amount of truth maintenance if action is to be taken. It is not clear, however, whether models that are based on the concept of string or chronicle can indeed cope successfully with the computational divergence.

These are some of the trends toward formalized theories of action. Their impact will be enhanced by the added modeling possibilities offered by parallel architectures—in the form of distributed networks perhaps (Rumelhart, Smolensky, McClelland, & Hinton, 1986), or in the form of parallel rule-matching systems such as Soar (Laird, Newell, & Rosenbloom, 1987). In many respects these trends seem to match many of the psychological insights into the mental representation of time that I have reviewed in the preceding sections of this chapter, from concrete intentional action, to verisimilar scenarios, to representations of generative metaphors, and to formal conceptions of what time is. They provide the foundations for a more explicit and detailed theory about the processing of temporal information and the way humans stay tuned to the dynamic world around them.

SUMMARY AND CONCLUSIONS

In its first century, the experimental study of human time experience has been almost entirely a *psychophysics of duration*. Only recently, with the emergence of cognitive psychology, a much broader array of temporal phenomena has become the subject of empirical study, including the perception of rhythmic patterns, the planning of future action, and the narrative structure of complex events. In this chapter I have argued for the position that time as duration is in fact an advanced abstraction, a form of successions of real events, or episodes. If these events pertain to our personal history, this "narrative closure" leads to the identity of what we call our *self*. Cognitive representations of time span a continuum from highly verisimilar, concrete dynamic representation which derives from a functionally much more basic biological requirement: the need to stay in tune with a dynamic, unfolding outside world. Mental representations of time enable us to achieve behavioral and cognitive coherence of scenes, to semi-abstract analogical schemes, and from there to formalized, axiomatic theories of time. The remarkable instability of time's rate of flow is the most pronounced aspect of subjective time and the principal dependent variable of the psychophysics of time. It is derived from the use humans make of these various types of representation while they are "tuning in" on the sequential contingencies of their environment.

REFERENCES

- Aasman, J. (1988) Implementations of car-driver behaviour and psychological risk models. In J.A. Rothengatter & R.A. de Bruin (Eds.), *Road user behaviour: Theory and research* (pp. 106-118). Assen, The Netherlands: Van Gorcum.
- Bartlett, J. (1980). *Bartlett's familiar quotations* (15th ed.). Boston, MA: Little, Brown.
- Brockelman, P. (1985). *Time and self: Phenomenological explorations*. New York: Crossroad.
- Burns, L.D. (1979). *Transportation: Temporal and spatial components of accessibility*. Lexington, MA: Heath.
- Carbonell, J.G. (1982). Metaphor: An inescapable phenomenon in natural language comprehension. In W.G. Lehnert & M.U. Ringle (Eds.), *Strategies for natural language processing* (pp. 415-434). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Clark, H.H. (1973). Space, time, semantics, and the child. In T.E. Moore (Ed.), *Cognitive development and the acquisition of language* (pp. 27-63). New York: Academic Press.
- DiSessa, A. (1983). Phenomenology and the evolution of intuition. In D. Gentner & A.L. Stevens (Eds.), *Mental models* (pp. 15-33). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Fraser, J.T. (1982). *The genesis and evolution of time: A critique of interpretation in physics*. Amherst, MA: University of Massachusetts Press.
- Freyd, J.J. (1987). Dynamic mental representations. *Psychological Review*, 94, 427-438.
- Georgeff, M.P., & Lansky, A.L. (Eds.). (1987). *Reasoning about actions and plans*. Los Altos, CA: Morgan Kaufmann.
- Gibbon, J., & Allan, L. (Eds.). (1984). Timing and time perception. *Annals of the New York Academy of Sciences*, Vol. 423. New York: New York Academy of Sciences.
- Gibson, J.J. (1969). *The ecological approach to visual perception*. Boston, MA: Houghton Mifflin.
- Gibson, J.J. (1975). Events are perceivable but time is not. In J.T. Fraser & N. Lawrence (Eds.), *The study of time II* (pp. 295-301). New York: Springer-Verlag.
- Goodman, N. (1984). *Of mind and other matters*. Cambridge, MA: Harvard University Press.
- Gould, S. J. (1987). *Time's arrow, time's cycle: Myth and metaphor in the discovery of geological time*. Cambridge, MA: Harvard University Press.
- Gruber, J.S. (1976). *Lexical structures in syntax and semantics*. Amsterdam: North-Holland.
- Grünbaum, A. (1968). *Modern science and Zeno's paradoxes*. London: Allen & Unwin.
- Guyau, J.-M. (1988). *La genèse de l'idée de temps. [The origin of the idea of time]*. In J.A. Michon, V. Pouthas, & J. L. Jackson (Eds.), *Guyau and the idea of time* (pp. 37-90; translation pp. 93-148). Amsterdam: North-Holland Publishing Company. (Original work published 1890).
- Hobbs, J.R., & Moore, R.C. (1985). *Formal theories of the common sense world*. Norwood, NJ: Ablex.
- Holland, J.H., Holyoak, K.J., Nisbett, R.E., & Thagard, P.R. (1986). *Induction: Processes of inference, learning, and discovery*. Cambridge, MA: MIT Press.
- Horwich, P. (1987). *Asymmetries in time: Problems in the philosophy of science*. Cambridge, MA: MIT Press.
- Jackendoff, R. (1983). *Semantics and cognition*. Cambridge, MA: MIT Press.
- Jackson, J.L. (1986). *The processing of temporal information*. Doctoral Dissertation University of Groningen, The Netherlands.
- Johnson-Laird, P.N. (1983). *Mental models*. Cambridge: University of Cambridge Press.
- Jones, M.R. (1976). Time, our lost dimension: Toward a new theory of perception, attention, and memory. *Psychological Review*, 83, 323-355.
- Jones, M.R. (1985). Structural organization of events in time. In J.A. Michon & J.L. Jackson (Eds.), *Time, mind, and behavior* (pp. 226-241). Berlin: Springer-Verlag.
- Jones, M.R., & Boltz, M. (1989). Dynamic attending and responses to time. *Psychological Review*, 96, 459-491.
- Laird, J.E., Newell, A., & Rosenbloom, P.S. (1987). Soar: An architecture for general intelligence. *Artificial Intelligence*, 33, 1-64.

- Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago, IL: University of Chicago Press.
- Langley, P., Simon, H.A., Bradshaw, G.R., & Zytkow, J.M. (1987). *Scientific discovery: Computational explorations of the creative process*. Cambridge, MA: MIT Press.
- Lansky, A.L. (1987). A representation of parallel activity based on events, structure, and causality. In M.P. Georgeff & A.L. Lansky (Eds.), *Reasoning about actions and plans* (pp. 123-159). Los Altos, CA: Morgan Kaufmann.
- Larkin, J., & Simon, H.A. (1987). Why one picture is worth more than ten thousand words. *Cognitive Science*, 13, 63-100.
- Lawrence, N. (1986). The origins of time. In J.T. Fraser, N. Lawrence, & F.C. Haber (Eds.), *Time, science, and society in China and the West: The study of time V* (pp. 23-38). Amherst, MA: University of Massachusetts Press.
- Luria, A.R. (1968). *The mind of a mnemonist*. New York: Basic Books.
- Macar, F. (1985). Time psychophysics and related models. In J.A. Michon & J.L. Jackson (Eds.), *Time, mind, and behavior* (pp. 112-130). Berlin: Springer-Verlag.
- Mashhour, M. (1964). *Psychophysical relations in the perception of velocity*. Stockholm: Almqvist & Wiksell.
- McCarthy, J.M., & Hayes, P.J. (1969). Some philosophical problems from the standpoint of artificial intelligence. In D. Michie & B. Meltzer (Eds.), *Machine intelligence* (Vol. 4, pp. 463-502). Edinburgh: Edinburgh University Press.
- Michon, J.A. (1967). *Timing in temporal tracking*. Assen, The Netherlands: Van Gorcum.
- Michon, J.A. (1985). The compleat time experimenter. In J.A. Michon & J.L. Jackson (Eds.), *Time, mind, and behavior* (pp. 20-52). Berlin: Springer-Verlag.
- Michon, J.A. (1988). Should drivers think? In J.A. Rothengatter & R.A. de Bruin (Eds.), *Road user behaviour: Theory and research* (pp. 508-517). Assen, The Netherlands: Van Gorcum.
- Michon, J.A., & Jackson, J.L. (1984). Attentional effort and cognitive strategies in the processing of temporal information. In J. Gibbon & L. Allan (Eds.), *Timing and time perception. Annals of the New York Academy of Sciences* (Vol. 423, pp. 298-321). New York: New York Academy of Sciences.
- Michon, J.A., Pouthas, V., & Jackson, J.L. (Eds.). (1988). *Guyau and the idea of time*. Amsterdam: North-Holland Publishing Company.
- Miller, A.I. (1986). *Imagery in scientific thought*. Cambridge, MA: MIT Press.
- Miller, I. (1984). *Husserl, perception, and temporal awareness*. Cambridge, MA: Bradford Books/MIT Press.
- Montangero, J. (1977). *La notion de durée chez l'enfant de 5 à 9 ans [The notion of time in 5- to 9-year old children]*. Paris: Presses Universitaires de France.
- Montangero, J. (1985). The development of temporal inferences and meanings in 5- to 8-year old children. In J.A. Michon & J.L. Jackson (Eds.), *Time, mind, and behavior* (pp. 279-287). Berlin: Springer-Verlag.
- Morris, R. (1985). *Time's arrows: Scientific attitudes toward time*. New York: Simon & Schuster.
- Neustadt, R.E., & May, E.R. (1986). *Thinking in time: The uses of time decision makers*. New York: Free Press.
- Nowotny, H. (1989). Mind, technologies and collective time-consciousness. In J.T. Fraser & L. Rowell (Eds.), *Time and mind: Interdisciplinary issues (The study of time VI)* (pp. ???-???) . Madison, CT: Associated Universities Press.
- Park, D. (1985). Brain time and mind time. In J.A. Michon & J.L. Jackson (Eds.), *Time, mind, and behavior* (pp. 53-64). Berlin: Springer-Verlag.
- Piaget, J. (1946). *Le développement de la notion de temps chez l'enfant [The child's conception of time]*. Paris: Presses Universitaires de France.
- Prigogine, I. (1980). *From being to becoming: Time and complexity in the physical sciences*. San Francisco: Freeman.
- Pylyshyn, Z. (1988). *The frame problem*. Hillsdale, NJ: Lawrence Erlbaum Associates.

- Reason, J.T., & Embrey, D.E. (1985). *Human factors principles relevant to the modelling of human errors in abnormal conditions of nuclear and major hazardous installations*. Report prepared for the European Atomic Energy Community under contract EC1 1164-B7221-84-UK. Dalton, Lancashire, England.
- Richardson-Klavehn, A., & Bjork, R.A. (1988). Measures of memory. *Annual Review of Psychology*, 39, 475-543.
- Rifkin, J. (1987). *Time wars: The primary conflict in human history*. New York: Henry Holt.
- Rosen, R. (1985). *Anticipatory systems: Philosophical, mathematical and methodological foundations*. Oxford: Pergamon Press.
- Rumelhart, D.E., Smolensky, P., McClelland, J.L., & Hinton, G.E. (1986). Schemata and sequential thought processes in PDP models. In J.L. McClelland & D.E. Rumelhart (Eds.), *Parallel distribute processing. Vol. 2: Psychological and biological models* (pp. 7-57). Cambridge, MA: Bradford Books/MIT Press.
- Schacter, D.L. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 13, 501-518.
- Schank, R.C. (1982). *Dynamic memory: A theory of learning in computers and people*. Cambridge: Cambridge University Press.
- Schank, R.C. (1986). *Explanation patterns: Understanding mechanically and creatively*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Shaffer, L.H. (1985). Timing in action. In J.A. Michon & J.L. Jackson (Eds.), *Time, mind, and behavior* (pp. 226-241). Berlin: Springer-Verlag.
- Shepard, R.N. (1984). Ecological constraints on internal representation: Resonant kinematics of perceiving, imagining, thinking, and dreaming. *Psychological Review*, 91, 417-447.
- Sherover, C.M. (1975). *The human experience of time: The development of its philosophic meaning*. New York: New York University Press.
- Szamosi, G. (1986). *The twin dimensions: Inventing time and space*. New York: McGraw Hill.
- Teulings, H.-L. (1988). *The analysis of handwriting*. Doctoral Dissertation, University of Nijmegen, The Netherlands.
- Thomassen, A.J.W.M., & Teulings, H.-L. (1985). Time, size, and shape in handwriting: Exploring spatio-temporal relations at different levels. In J.A. Michon & J.L. Jackson (Eds.), *Time, mind, and behavior* (pp. 253-263). Berlin: Springer-Verlag.
- Treisman, M. (1963). Temporal discrimination and the indifference interval: Implications for a model of the internal clock. *Psychological Monographs*, 77 (Whole no. 576).
- Van Benthem, J.F.A.K. (1983). *The logic of time*. Dordrecht, The Netherlands: D. Reidel.

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