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The compleat time experiencer

John A. Michon

1 Prologue

What is it like to be a Time Experiencer? In a well known article about consciousness Thomas Nagel (1974) raised the fascinating question what it would be like to be a bat. A similar question can be asked with respect to human time consciousness. If our experience of time would turn out to be something that is conceptually unitary, in the sense that it can be defined by a distinct set of related events, attributes, or processes, then it must mean something, however little, to be a Time Experiencer.

If we practice psychology as a 'science of the artificial', to use Herbert A. Simon's (1969) phrase, the study of time becomes essentially a matter of designing a temporal interface between the human organism and the external world. The ultimate problem of time psychology then is to demonstrate that the human mind operates in such a fashion that it can cope with the temporal contingencies of its natural and self-created environments and that, at the same time, it does produce the experiential appearances of time which conscious reflection and observation reveal. This would have to include such 'products' as the conscious experience of present, past and future, the rate at which time is felt to pass, but also the possibility of such 'pathologies' as déja-vu and stasis, viz. the apparent freezing of time. And it would also have to deal with the insight that some of these 'products' may themselves serve as aids in the coping process. This problem statement leads me to the following working definition of psychological time:

> Time is the conscious experiential product of the processes which allow the (human) organism to adaptively organize itself so that its behavior remains tuned to the sequential (order) relations in its environment.

The remainder of this chapter is aimed at clarifying this definition in the context of a general overview of some of the pertinent issues in time, mind, and behavior. The famed Japanese psychologist Masanao Toda once said: “Obviously, trying to 'define' time is a fool's errand. To define a notion is to find for it an equivalent ideational construct made of some other, usually more primitive, notions (...) Any attempt to define time, therefore, is bound to be ridiculous, since nothing in this world even remotely resembles time" (Toda, 1978, p. 371/2). In order to avoid the impression that I am about to embark on a fool's errand, I wish to point out that we need not define time at all in the manner suggested by Toda. Instead time may be defined operationally, namely by what it is that generates our experiences and notions—actual and potential—of time. That is, we may attempt to explain time in terms, not of notions, but of mechanisms and processes, specifically those that provide adequate tuning of the organism to its environment.

2 The Physical Fundament of Time Experience

2.1 Introduction

Time appears to imply more than is structurally available in reality. It primarily seems to constitute a quality of experience. Indeed there has been a persistent debate among philosophers about the ultimate status of time. Is time a mental construction, an illusion if you like, imposed on reality as human experience it? Or is it (also) a fundamental property of the physical world, independent of who or what is looking at it?

2.2 The Reality of Time's Arrow

The debate about the status of time as a property of nature is vacillating between the poles of Becoming and Being which, for brevity's sake, may be qualified as the respective positions pro and con the intrinsic directionality of time. The issue is simply whether or not sequential order is a structural feature of the universe or not, known as the problem of 'time's arrow'. In this debate physicists have, by and large, taken sides with the ideologues of Being, consistently trying to eliminate temporality as an inherent property of the universe from their theories. Not only is Newtonian mechanics, the fundament of classical physics, neutral with respect to the direction of time, but Einstein's relativistic mechanics is so too.

Even the evidence for a genuine break of time symmetry, among other things contained in the second law of thermodynamics, has been attacked. Gibbs (1902), for instance, argued that the intrinsic time-asymmetry of thermodynamics must be an illusion caused by the poor acuity of the observer's sense organs. If we throw a dash of milk into a cup of tea and stir, the result will be a most distasteful looking, opaque liquid that cannot be unstirred anymore. Looking through a microscope, however, we would still observe heterogeneity: milk droplets in an ocean of tea. Although Gibbs' objection has not stood up to criticism, arguments like his have induced Prigogine (1980) and others to propose that a fundamental time asymmetry must exist even at the quantum level. But this proposal, in turn, has met with criticism too. Davies (1981), who otherwise appears to have no difficulty in accepting the idea that the break of time symmetry is real, has qualified Prigogine's work as an attempt "to find a mysterious extra ingredient, absent in hitherto known physics, to make the world inherently asymmetric as it evolves" and this, in Davies' view, "entails putting the asymmetry in by hand" (p. 69).

And so the battle rages on, most recently in a domain known as quantum gravity, where the very large and the very small meet (see e.g. DeWitt, 1983; Freedman & van Nieuwenhuizen, 1985). If the effort to unify gravity with the other three fundamental forces of nature into one geometrical framework would meet with success, physics would once more eliminate time. But the fundamental geometrization of physics would do more. If what happens in the universe can be accounted for directly by the global geometrical properties of space-time, rather than by the local attributes of objects or events, the need for an observer 'interpreting' these objects and events would evaporate at the same time. This brings me close to some of the points raised by David Park (1985) in chapter 3 of the present volume. Park argues that since physics cannot do without the concept of a conscious observer, for reasons which he explains, psychology must play a role in the construction of physical theory, whether physicists like it or not.

It occurs to me, however, that the break in time-symmetry keeps turning up faster than physical theory succeeds in explaining it away. This leaves me with a strong feeling that time must indeed be an inherent property of nature, a fundamental break of symmetry, justifying in an objective way the distinction between earlier and later. Furthermore, 'time's arrow' is seen to touch immediately upon the problem of 'The Observer' in physical theory, an entity that is required to provide an interpretation of what happens and of the sequence in which things happen. Perhaps it is therefore safe to conclude that we must assume sequential order to be an inherent property of reality, but that it takes a conscious observer to recognize it.

2.3 Psychological Extras

Assuming that the order of events is indeed physically determined (albeit perhaps under certain local constraints such as the particular inertial frame of reference of the observer), the task of the time psychologist is simply to establish how this 'real' order is coded and represented, what mechanisms are involved in the process, and how these produce the phenomenology of time experience discussed earlier.

Unfortunately the matter is not simple at all. As Davies (1981, p. 63) pointed out, "if our conception of reality is based on our experience of time ... it is seriously at odds with the external world whose reality we are concerned with ... Psychological time possesses apparent qualities that are absent from the 'outside' world of the laboratory. This additional structure consists of an awareness of a now or present moment, and an impression that time passes." These two qualities, which I shall call now and flow, are additions to the world as we perceive it in absence of specific physical stimuli that could possibly generate them. As such they seem to constitute a sort of 'minimal set' of the experiential modes of time, although this privileged status does not a priori exclude other qualities that would turn out not to be reducible to either now or flow.

The initial problem of time psychology, formulated in the prologue has now been reduced, at least provisionally, to the following goal: establish how 'real' order is coded and represented, and what mechanisms are involved in this process, such that now and flow result as attributes of experience. Instead of directly pursuing this goal, I shall adopt a rather more circumambulant approach. After specifying in more detail what people mean when they say they are experiencing time I shall consider why and how Time Experiencers, such as humans, can function when dealing with an ordered environment. This will lead to the conclusion that a biopsychological explanation in terms of adaptive mechanisms for temporal control does not carry us far enough. A different domain of discourse is required, leading into a consideration of time as information—and humans as information processing systems. Beyond that, however, a third level of theoretical consideration will be needed, one that can accommodate the structural properties of the events that are to be coped with by the individual Time Experiencer.

3 The Phenomenology of Time Experience

3.1 Introduction

For a theory that can account for time-as-experienced as well as for the tuning processes that generate this experience to be successful, we must first specify the proper domains of discourse for each aspect. For that purpose, time-as-experienced will be considered from an intentional stance, while the underlying processes will be looked at later from a functional point of view.

3.2 Intentional Systems

A behaving system is called intentional and someone observing such a system is said to adopt an 'intentional stance', if it is possible to ascribe to it rational beliefs, or feelings, or intelligence and if on that basis only it is possible to predict the behavior of that system (Dennett, 1978). Whether or not the system under concern 'really' has these beliefs, etc., is immaterial. Moreover, the intentional stance does not require statements about the functions and processes that generate the observed (rational) behavior. Actually, mixing intentional and functional theory is considered extremely bad practice and it should therefore be rigorously avoided (Herrmann, 1982; Michon, 1984). The reason is that the resulting mixture will necessarily be infested with homunculi, a pernicious race of question begging entities: “Whenever a theory relies on a formulation bearing the logical marks of intentionality, there is a little man concealed”, Dennett warns us. (1978, p. 12).

In Dennett's view “intentional theory is vacuous as scientific psychology because it presupposes and does not explain rationality or intelligence”. (1978, p. 15). This does not imply that intentional theory as such is inadmissible. Consistent intentional theory, genuine phenomenological explanation capable of predicting behavior, is perfectly well feasible and quite common in the social sciences, but ultimately it cannot count as scientific psychology for the stated reason. Scientific psychology—or perhaps we should say psychonomics—must therefore occupy itself with the elimination of intentional theory by replacing it with functionalistic explanation by adopting what Dennett has called the 'design stance' or the 'sub-personal stance'. There is a second way of eliminating intentional theory, namely by means of structuralistic explanation; incidentally, this is precisely the way in which physicists have been trying to get rid of time. As we shall see later in this chapter, however, that road is blocked with another type of difficulty: structural theory does not necessarily qualify as psychonomics either (Michon, 1984).

Dennett (e.g. 1981) has come to distinguish two levels of intentional theory. At the first level we find the naive behavioral explanations that are part of 'folk psychology' and at the second level we have the expurgated versions thereof, namely those explanations which have passed critical examination by philosophers, social scientists and humanists. I shall briefly consider both versions in the light of our present topic, time experience.

3.3 UNEXPURGATED DESCRIPTIONS OF TEMPORAL EXPERIENCE

Time figures prominently in experience. Quite a number of temporal impressions that commonly occur in everyday life are fairly dramatic or at least accessible even to naive introspection. The déja-vu, for instance, experienced occasionally by most people, as is the feeling of 'queer coincidence' which C.G. Jung (1960) described in his study on synchronicity, a non-causal structural connection between simultaneous events. The powerful impact of rhythm on behavior seems to be universal. Time experience is also drastically affected when people are involved in stressful or blissful events. And there are many other equally conspicuous manifestations of time.

In a thoughtful paper Gorman & Wessman (1977) have discussed the rich variety of temporal concepts and expressions that ordinary people use when discussing time in their daily lives. These range from the simple, familiar representations of time as a line or a circle, and time as money or boredom, to such fancy metaphors as 'time is a shooting star', an 'ever branching tree', a 'Bach cantata', or a 'chronic thief' (Wessman & Ricks, 1966, pp. 117-120). The phenomenology provided by folk psychology is simply overwhelming, and many authors have indeed argued that experiential time, in their opinion, cannot be a unified concept. In short, there appears to be quite a lot more in everyday experience than just now and flow.

3.4 ARTISTS' IMPRESSIONS: TIME AND NARRATIVE

To whom should we turn when it comes to Dennett's expurgated variety of 'folk psychology'? There seem to be two roads to travel: art and science.

Time is thoroughly anchored in art, not only in the so called temporal arts—music, dance and cinematography—but also in painting (e.g. Baudson, 1984; Goodman, 1984) and literature (Ricoeur, 1983). The significance of the time artists resides in their attempts to manipulate time in their self-created universes in ways that are internally consistent and that, consequently, appear plausible to the spectator or the reader. Thus, the appreciation of a work of art resembles the thought experiments (Gedankenexperimente) in science, and the requirement of internal consistency qualifies the genuine work of temporal art as an expurgated variety of intentional theory. As an example let us consider time in narrative, the home territory of the time novelist. A time novelist is someone who composes narrative in which explicit time experiences of the protagonists are crucial determinants of the action and the context. Such authors—among them true celebrities like Samuel Beckett, Marcel Proust, J.B. Priestley, Thomas Mann and John Fowles—can be seen to exercise a threefold command over temporal matters. In the first place the time novelist makes his or her characters experience time in a natural way, but on a magnified scale: they are subject to, but also intensely aware of, day and night, the seasons, their lives passing, and so on. Even their decisions to leave a party or to take the early train are seen in the existential light of time: order, delay, and “how long it takes”. In the second place, in order to evoke such experiences in a character, the author creates conditions in which the experiences are plausible. In other words, the protagonists must be endowed with belief structures and behavioral goals that will closely and rationally accommodate their patterns of activity (or perhaps sometimes deliberately not, as in Gogol's Diary of a Fool). Errors destroy the narrative: even naive readers are quite sensitive to ruptures in the fabric of story time. Finally the author creates, by stylistic means, concurrent temporal experiences in the reader and thus, among other things, enhance the reader's identification with one or more characters. Authors can induce feelings in an audience of time passing when the protagonist feels it pass, or time dragging when the story requires it to drag, and so on. In other words, the narrative does not only describe temporal facts and relations, but it wishes to evoke a temporal experience in the reader that will fit the intrinsic, generative structure of the narrative as needed (see also Michon 1985, Chapter 20 of the present volume).

In this context it is interesting to mention John Fowles' observation that writers are essentially playing godgames. Such godgames are essentially time games, as Fawkner (1974, p. 118) remarked, because from a fundamental dissatisfaction with the world as it is, the writer creates “a past that never was ... Even the simplest and shortest act of literary text, as brief as a haiku, is a surreptitious bid for immortality, or freedom from ordinary time”. (Fawkner, 1984, p. 10). If, perhaps, ancient cultures may not have felt the need for gods who were in command of time (Toda, 1978; see also Michon & Jackson (1985, chapter 1 of the present volume), they seem to flourish in modern literature and theater, where the sacred unity of time, place and action has been abandoned.

3.5 Scientists' Expressions: Phenomenological Taxonomies

Although we may have to cope with an abundance of intentional descriptions of naive time experience, psychologists and anthropologists have tried to organize time experience in somewhat more parsimonious terms, aiming for a taxonomy of expurgated folk psychology.

Orme (1969), for instance, reduced the substantial variety of phenomenological time experiences in thirteen more or less independent classes of phenomena. Although his taxonomy incorporates most of the subjective, temporal phenomena, there is no underlying principle which could tie these various manifestations of time together.

Exactly the opposite is found in the beautifully symmetric taxonomy of time which does appear in a book on the Patterning of Time by the anthropologist Doob (1971). I cannot even begin to describe or explain the intricate relations that are implied by Doob's taxonomy. Fortunately Doob himself has provided a very compact summary (o.c. p. 407-409) to explain the diagrammatic representation of Figure 1. Faced with such complexity we stand in awe: Doob has certainly succeeded in providing an orderly picture. But, although it imposes order, it does not relate in a functional way to the empirical findings it is supposed to accommodate.

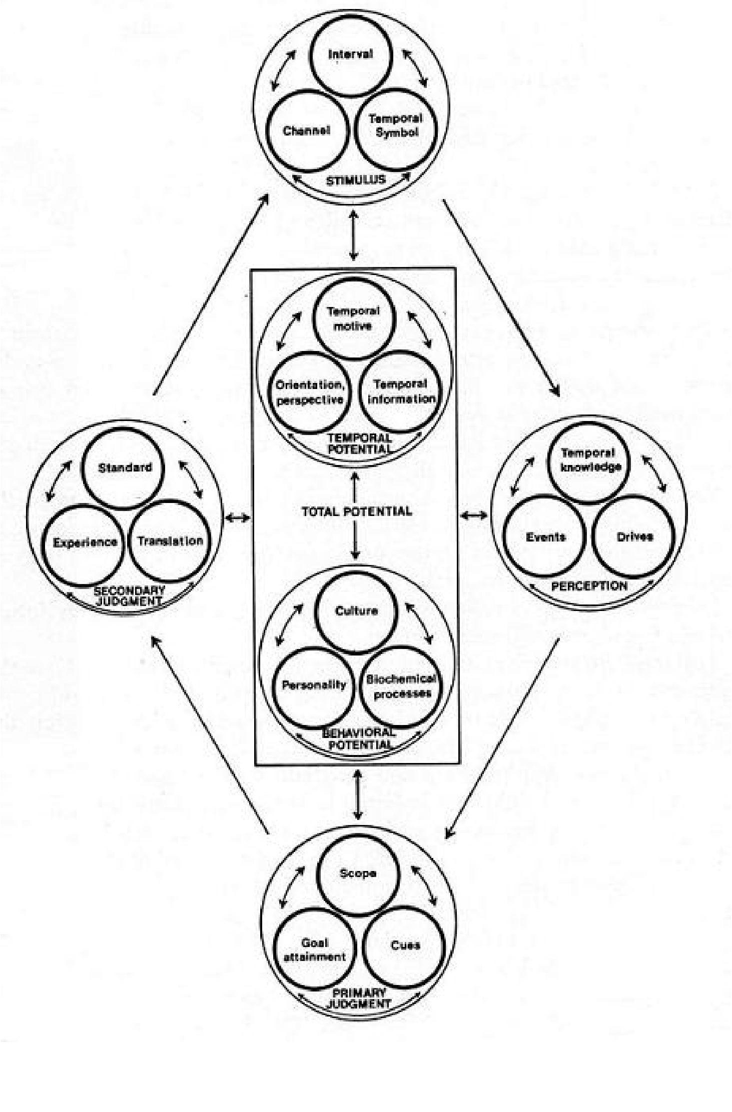

Figure 1. A taxonomy of time
(From: Doob,1971, p. 31; reprinted by permission).

3.6 RICH AND POOR PHENOMENOLOGIES: CAN TIME BE MODELLED?

Although we are apparently living with an extremely rich temporal world we, perhaps, need perhaps not give up our attempts to organize time experience in somewhat more parsimonious terms. Gorman & Wessman (1977) have indeed proposed that we do not necessarily have to adopt a pluralistic view of time experience: “We should view temporal symbols not as distorted or altered perceptions of a determinate thing called 'time' but rather as representations chosen and constructed by individuals as apt expressions of their own life situations and feelings. Not only do the symbols used reflect the cultural context in which the person is operating, it seems even likely that he will use different concepts and symbols depending on particular activities that he is engaged in. Each may require a different approach to temporal information and consequently a different set of cognitive operations. This would turn temporal concepts into state variables, pointing to the type of operation being performed on temporal reality when the person is in a particular state” (p. 238).

Stated in terms that are relevant to our discussion thus far, we are facing the question: How easy is it to construct a functional model of the adaptive tuning process, such that this model will appear as a convincing 'time experiencer' to an onlooker adopting the 'intentional stance'? The answer depends to a large extent on how easily people will ascribe intelligent or rational temporal beliefs and attitudes, such as 'punctuality' or 'future-orientedness', to such a model.

Generally speaking it is simple to design a functional model for a particular behavioral domain with respect to which observers are prepared to adopt the intentional stance, when the behaviors to be modeled have a poor phenomenology. For instance, people do not differ a great deal in what we think they are doing when they do sums or crosswords. Such activities have poor phenomenologies, and consequently there can be a fair amount of agreement as to the intelligence or the belief structures that we ascribe to a system that can perform such tasks. In contrast experiences which have rich phenomenologies, such as pain, or dreams, or consciousness, cannot easily be incorporated in models that will elicit the intentional stance in an arbitrary observer. If your 'real pain' is entirely different from my 'real pain' how could there ever be a robot to which both you and I are willing to ascribe the suffering of 'real pain'?

The question is therefore: how rich is the phenomenology of time experience 'really'? If it is as rich as the preceding two sections suggest, that is, if my time is very unlike your time, or even worse, if my time today is very unlike my time tomorrow, then there can be no hope for a general process model that will convincingly generate all or most of the phenomenology of time experience. If we find that time experience has many so called program resistant aspects, and if we cannot reduce that phenomenology to something much 'poorer' it will be a hopeless task to design a general time experiencer. Even in that case it may be possible to specify a number of specific domains of temporal experience, each of which will turn out to be accessible to functional analysis. If that is the case we may still be able to construct a 'compleat time experiencer', although its completeness will be rather trivial, the whole being just the sum of its (modular) parts and no more.

4 Biopsychological basics

4.1 Adaptation and tuning

There is a principle, formulated by Wonham (1976), which tells us that any system that is to maintain its internal structure and at the same time is to interact adaptively with its environment, must have a sufficiently complex representation of its environment incorporated in its feedback circuits. This does not imply, of course, that such a representation is necessarily of a cognitive nature. It only points to the necessary presence in the human organism of mechanisms or processes that we can perhaps best characterize as internal clocks, counters and relays, entities that help us to maintain our personal integrity in the face of change.

Physical reality is reflected in the domain of organic life. Consequently, if physical reality is indeed intrinsically time-asymmetric, as I proposed earlier, any life form must be intrinsically time-asymmetric too.

There is more, however. Organisms maintain their internal structures over a comparatively wide range of external circumstances, and the evolution of such systems tends generally towards greater complexity and increasing functional independence from environmental contingencies (Goodwin, 1983; Saunders & Ho, 1976). In the first place this has provoked the development of defensive mechanisms against local differences in the more or less permanent environmental conditions, such as the salinity of the ocean (outer membranes and skins), pressure (skeletons), or ultraviolet radiation (pigmentation).

More interestingly for the present discussion, nature apparently also succeeded in developing adaptive mechanisms for coping with the comparatively fast changes in the terrestrial environment, diurnal, tidal and seasonal variations in particular. Although the addition of such 'biological clocks' to the genetic and behavioral repertoire of a life form already creates a considerable degree of functional independence, a further important step was taken when some species acquired the capability of storing experiences for later use under appropriate circumstances (Richter, 1965). The possibility to internally represent the temporal structure of events (which is perhaps inherently related to the emergence of neural structures) was a decisive step on the road towards temporal control of the environment, that is, towards the ability to negotiate the kinds of temporal contingencies that are not imbedded in such outspoken cyclical patterns of events as the day-night cycle or the solar year.

The process of gradual internalization of environmental variations in a form of 'internal representation' creates conditions that allow the optimalization of the organism's functions. At the same time, however, it also creates a new problem. In order to remain in pace with the flow of events in the outer world, a very sharply tuned 'interface' with the environment is required. At some point in time, namely the point which we call now or present, there must be a close-to-perfect correlation between what is happening outside the individual and the representation thereof 'inside'. Any species that would be incapable of tuning its internal events to those in the outer world would stand as much chance in evolution as the proverbial soluble fish (and pretty much for the same reason).

Let us now turn to a closer consideration of the temporal tuning aspect that, in my view, constitutes the rock bottom for temporal experience. Tuning involves matching events in the outside world events with the corresponding mental events. This, in a very generic and abstract sense, suggests that tuning is in principle a complicated form of time measurement. Time measurement essentially involves two independent series of successive events, the measurement consisting of observing the simultaneity of an event (p) in one series with an event (p') in the other, followed by another observation of such a simultaneous event pair q, and q' (Fraser, 1982). Using one of the event series as a reference, the interval between the events p and q can be expressed in terms of the number or density of events between p' and q' or vice versa. Tuning can be described as the process of keeping track of the correspondence between events in the outside world and the events produced in an internal representation of that world: keeping the two series in synchrony is precisely what tuning is about.

The necessity of tuning lies at the root of the elementary experiences of 'now' and 'flow'. The interval over which the organism succeeds in directly relating successions of internal and external events determines the width of the now or 'specious present'. Thus, the present may be seen as a dynamic interface, the 'window' which interfaces external and mental (internally represented) events. Depending on the state the organism is in and the structure of the event sequence, the width of this window may vary, and the length of the experienced 'present' will vary accordingly. At same time, since the matching of external and internal events involves time measurement in the proper sense, it may be assumed that the experience of time flow as fast or slow depends on the relation between these two series of events. If the internal events tend to be relatively earlier with respect to their corresponding external events than would be expected on a chance basis, time would seem to flow slowly, and similarly if the internal events would frequently be (too) late relative to their external counterparts, the corresponding experience would have to be one of time flowing fast.

A concomitant aspect of tuning is that it allows the organism to select a time base in synchrony with the 'pulse' or 'rhythm' of events, thereby freeing it to do other things in between the instants at which perfect coincidence is crucial. This is of great importance in skilled activities such as musical performance, handwriting and speech perception. The chapters by Povel (1985, chapter 14), Shaffer (1985, chapter 15), Nooteboom (1985, chapter 16) and Thomassen & Teulings (1985, chapter 17) discuss this point in considerable detail.

4.2 Mechanisms for Temporal Control

The nature and development of the means that made the higher animals and humankind relatively independent of the vicissitudes of a sequential environment are discussed at length in chapter 4 (by Groos & Daan, 1985), Chapter 5 (by Richelle et al., 1985), and Chapter 6 (by Pouthas, 1985) of this volume. These chapters deal with the biopsychological fundaments of psychological time, and from them we learn that the adaptation of complex organisms, such as humans, to the temporal requirements of their habitats depends on both endogenous and acquired periodicities (biological rhythms or clocks) that are deeply rooted in their physiology and their anatomy. They tend to be phylogenetically ancient, permanent and resistant to external driving except at a narrow range of frequencies. These 'clocks' appear to control temporal adaptations to events in the range from one hour upward. Shorter intervals, on the other hand, rely on a rather different type of temporal regulation, for which no predetermined 'clocks' are available. Instead, it appears that different species, but also different individuals of a particular species, and even the same individual on different occasions, select a 'time base' from a multitude of potentially available, recurrent or non-recurrent counting and inhibitory delay (waiting) mechanisms.

Much of the temporal regulation of behavior appears already comparatively early in life. In young animals, as well as in human infants adequate temporal control can be observed at an early age, although stable temporal performance is usually acquired fairly late in life. In the human child this state is reached at about 8 years of age (see Pouthas, 1985, chapter 6 of the present volume). This would seem to imply that the selection of an appropriate time base form the available multitude requires a certain degree of maturity plus, no doubt, quite some practice.

Richelle & Lejeune (1980) and their associates have dealt with the various categories of temporal regulation in considerable detail. Broadly speaking they distinguish between physiological and behavioral mechanisms. Within the first category a further division is made between central mechanisms which in part seem to be located in the septal and hippocampal regions of the brain, or are at least observable in the electrical activity of the cortex. Somewhat disappointingly perhaps, there is little evidence for a relation between timing and such conspicuous periodical phenomena as the brain's alpha rhythm. Rather it seems that certain event related cortical responses, viz. the contingent negative variation, also known as the 'expectancy wave', are in some way related to the ways in which a person is coping with the temporal requirements of the environment (see e.g. Macar, 1980; also Macar, 1985, chapter 7 of the present volume).

Among the peripheral physiological mechanisms discussed in Richelle & Lejeune (1980) heart rate plays a prominent role. The relation between the regularity of cardiac activity and mental effort has been thoroughly established (e.g. Mulder & Mulder, 1981). It has also been found that many simple motor responses occur in phase with the cardiac cycle. It remains unclear, however, whether this is in fact due to a specific pacemaker (Zeitgeber) function of the peaks in the cardiac response.

Within the second category of temporal regulatory mechanisms mentioned by Richelle & Lejeune (1980) three subgroups may be distinguished, to wit, proprioceptive mechanisms, collateral behaviors, and (external and internal) temporal cues. Proprioceptive temporal controls make use of the various feedback circuits that can be established in the sensori-motor system, and they play a fundamental role in skilled behaviors such as writing and musical performance. Collateral behaviors, the second subgroup in the category of behavioral mechanisms, are important for temporal control of behavior, although they bear no direct relation to the action that is being timed. Pacing up and down, scratching, finger tapping while waiting for something to happen constitute powerful aids in correct temporal performance. Constraining the subject so as to prevent this collateral behavior has a very negative effect on the temporal precision of the subject's actions, which is overcome only when a new collateral pattern can be developed within the prevailing constraints (Frank & Staddon, 1974; Glazer & Singh, 1971). Rather than being a kind of behavioral clock or a non-verbal way of counting—which pacing or finger tapping may easily appear to be—the received view of the functional significance of collateral behavior is that it serves to inhibit responses. In order that tension will not build up too high while the subject is waiting for something to happen or for an action to be taken, a (partial) release of tension is established by means of unrelated, permissible, so called 'displaced' behavior (see Richelle & Lejeune, 1980). As a final subgroup of temporal control mechanisms internal and external temporal cues should be mentioned. These include various forms of implicit or explicit counting, or more elaborate cognitive and environmental clocks and calendars.

The status as 'internal clock' of all physiological and behavioral mechanisms remains somewhat ambiguous. Many authors agree that subjects will select whatever mechanism will suit their needs (e.g. Macar, 1985, chapter 7 of the present volume): “multiple time bases are continuously constructed in response to the particular requirements of each situation and replaced by others when they become useless” (Richelle & Lejeune, 1980, p. 165).

4.3 Too Many Clocks

The number of different options available to the organism for establishing a time base for its performance in a particular timing task is apparently very large (Gooddy, 1958), and choices appear to be highly opportunistic (Richelle & Lejeune, 1980). Evidently we have reached the limits of a psychobiological explanation of human time experience in terms of 'clocks': there are no discernable rules that could explain why one 'clock' or 'clock system' would be preferred over another. A different frame of reference is needed, one which does enable us to understand how it is that different temporal conditions do elicit specific response patterns and strategies. Such a frame of reference is indeed available: time as information. And since we are aware of the fact that humans are a species of information processing systems it is appropriate to see if time experience can be understood as a manifestation of temporal information processing.

5 Time as Information

5.1 EQUIVALENCE

Behavior is under the control of time. Something is done simply because it is 1215 h rather than 1900 h, or because someone has waited 20 seconds rather than 10. In music and dance timing quality constitutes the difference between the delightful and the dreadful. Time, in other words, appears to have causative properties deriving from the temporal relations between the organism and its environment. Events that do not distinguish themselves except for their relative temporal position, as for instance in meter and rhythm, are found to have a strong effect on behavior when people are dancing or playing music. The power of rhythmicity can even be observed soon after birth. In short, temporal relations contain information and both humans and animals use this information to guide their behavior.

Fifteen years ago I formulated the 'equivalence postulate', explicitly stating the dual role of time: time as information in addition to its usual role as the ordering variable t in dynamic equations (Michon, 1972). In this view time has a status as relevant stimulation for the human organism that is not formally different from such extensive and intensive attributes as size, loudness or color. In other words, it is assumed that time is explicitly represented in the mind. At that time I understood this equivalence in a weak sense: stimuli were thought to possess an explicit temporal attribute. Since about 1977 this conception has been replaced by a much stronger equivalence; I now feel more strongly attracted to the idea that temporal information is encoded in a representational system of its own and that the encoding of sequential (or temporal patterns) takes place in a separate representational code which has come under study in the early seventies. Strong equivalence has found expression in the work, among others of Jones (1976, 1985, see chapter 13 of the present volume), and Anderson (1983) who entertains an interesting concept of temporal strings as a separate representational mode, to which I shall return later.

5.2 THE INFORMATION PROCESSING PARADIGM

Assuming the independent character of temporal information implies that the general features of information processing theory should also be generally applicable to temporal information processing as well. In recent years psychologists have formulated a rather substantial and internally consistent paradigm, known as cognitive psychology, which not only accounts for a extensive range of mental and behavioral phenomena, but also carries a considerable formal potential since it is narrowly related to the general theory of computation which also lies at the basis of computer science. The number and variety of models that have been based on the cognitive paradigm is quite considerable, but fortunately the basic features are pretty much the same in all of them.

The following capsule review has no other purpose than to introduce some of the basic features of this class of models to those readers who are not sufficiently familiar with this major trend in present-day experimental psychology. Much of the content of Time, Mind, and Behavior relies implicitly or explicitly on this or a related model (Figure 2).

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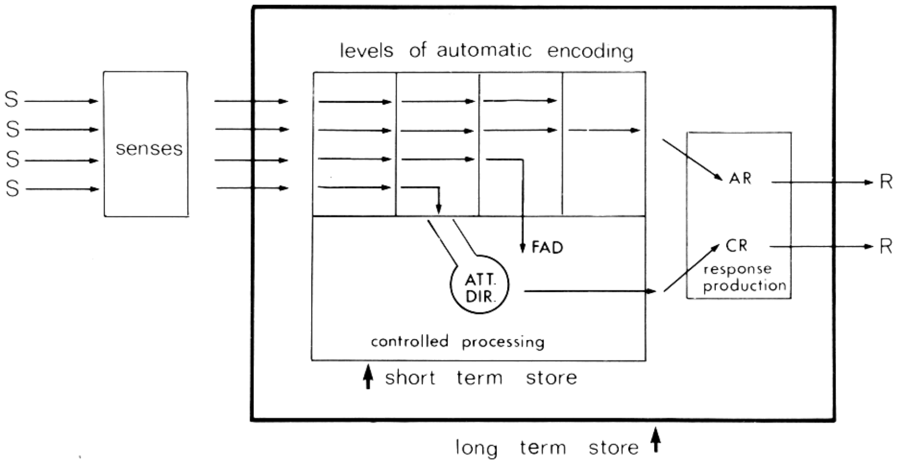

Figure 2. A general view of human information processing. Stimuli *(S)* reach the sensory systems (senses), which include iconic and echoic buffers. Subsequently information enters short-term or working memory, which is the active part of long-term memory. The input information is assumed to be analyzed at progressively deeper 'levels', much of it taking place automatically or habitually and leading to automatic responses *(AR)*. Attention is directed *(ATT.DIR.)* only to a small fraction of the information. This is the information that is processed under deliberate control and that may eventually lead to controlled responses *(CR)*. Since attentional capacity is limited some stimuli will not receive the attention they require, leading to a focal attention deficit *(FAD)*. (From van Zomeren, 1981; reprinted by permission).

Incoming stimuli (S) impinging on the receptor surfaces of the senses are subsequently buffered in a sensory register for a brief period of perhaps one second. In this memory buffer some superficial pre-processing filtering may take place. From the sensory register information is next transferred to a 'working memory' or 'short term store' for a progressively deepening analysis. Working memory is not a structurally isolated component within the memory system, but rather that part within the integral associative memory network which is active at a particular instant. Depending on the task to be performed, the process of analyzing the input information will, after some time, result in an overt or covert response. This may conclude an action cycle, and the information that was involved in it may subsequently be abandoned and 'leak' away in about 20 to 30 seconds unless, for some reason, it is kept in the active state through 'rehearsal' (silent or aloud). While information resides in working memory it can be consolidated, partly or in its entirety, as a result of repeated use or deliberate associative elaboration and so become a part of long term or permanent memory. In other words, it may leave a more or less robust trace, which can be reactivated associatively on a later occasion. Most information processing models distinguish between two basic processing modes: automatic and controlled (or deliberate). Automatic processing is seen as a fast process that can accept any number of simultaneous inputs and produces outputs almost instantaneously, in a more or less reflex-like fashion. Automatic processing requires no 'mental effort' and there seems to be no upper limit to the complexity of the inputs it can handle. By contrast, the controlled processing mode can handle inputs only in a serial fashion. It is a slow process, limited in its capacity and requiring conscious mental effort. The focus of attention can be determined by the nature of the task or by external or internal instructions. In addition, if for some reason the course of automatic information processing is interrupted, the controlled mode will take over in an attempt to restore the normal processing routines.

More detailed descriptions of the human information processing system along the lines of the model presented here can be found in any introductory text on cognitive psychology (see, for instance, Anderson (1985), Reed (1982), Lachman et al. (1979)).

5.3 Temporal Information Processing

Let us now turn again to the role that temporal information plays in information processing, fitting it to the general framework outlined in the previous section. Cognitive psychology appears to have come to a point where it accepts that at least three fundamentally different types of internal code or representation are in operation: mental images for coding spatial relations between items, abstract propositions for the encoding of meaning and temporal strings for encoding the order of items in a sequence (Anderson, 1983; p. 45-46). It is, of course, not surprising that temporal information is given a more or less independent status, but it is surprising that it has taken 'main stream' psychology so long to accept that fact (some reasons have been indicated by Michon & Jackson, 1985, chapter 1 of the present volume). What are the characteristics of these temporal strings? Anderson argues that they encode order, but not other aspects of time which, however, “is not to say that we cannot perceive or remember interval properties of a time sequence, but that such properties are not directly encoded in the structure of the temporal string ... Such information can optionally be encoded as attributes of the ordered elements.” (Anderson, 1983; p. 49).

Following this line of thought, the next question we are facing is what, in fact, constitutes the 'temporal attribute' encoded in these strings? The simplest assumption consistent with the idea of temporal strings is that the physically given order of events is the rock bottom cue on which temporal information processing is based. However, even if order would turn out to be a sufficient temporal stimulus, it cannot be the only relevant one. Logical or conventional (viz. proverbial or numerical) order, or even spatial arrangement may well provide (pseudo-)temporal cues that serve in those cases that order cues are lost or not available. If you put your cart in front of your horse, I will see your cart pass sooner than your horse, (at least on the assumption that the horse will persist in moving in its natural direction). If this temporal information is indeed encoded in terms of ordered strings, as is suggested by Anderson, other temporal attributes such as duration or temporal locus (position) being added if need demands, the question becomes how order can be encoded in the subject's mind. To answer this, one should realize that functionally the properties and organization of memory are such that there does indeed exist what would seem a sufficient condition for ordered events to be temporally encoded. If one event is perceived and subsequently retained in memory, the next event to be perceived will necessarily have the earlier event as part of its (remembered) context. Thus the earlier-later relation is represented as a stored-actual or old-new relation which has been used, implicitly or explicitly, by a great many authors from philosophers such as Saint Augustine, Husserl, and Merleau-Ponty, to experimental psychologists such as Janet (1928), Hintzman et al. (1975) and Tzeng et al. (1979) in order to account for the temporal organization of memory.

Recently there has been a tendency to assume that the encoding of earlier-later in terms of old-new is taking place automatically. In this light temporal information processing is seen as an automatic byproduct of the processing of other (categorical, propositional or spatial) information processing modes (Hasher & Zacks, 1979; Reed, 1982). This hypothesis attained a certain popularity, although it was based mostly on invalid assumptions and partly on unreliable empirical data. Moreover it stood almost totally in contrast with everything that was already known about the perception and judgment of time. Michon & Jackson (1984) produced detailed counterevidence. Independently, Zacks et al. (1984) have recently revised their original opinion and now appear to accept the idea that temporal information processing usually involves much hard cognitive work on the part of the subject. A balanced view of the issue is provided by Jackson (1985) in chapter 12 of the present volume. Her study makes abundantly clear that temporal information is indeed derived from various stimulus attributes, both at the lower levels of perceptual motor skill and at the cognitive level. Apart from individual differences in the selection of encoding and retrieval strategies there is a marked influence of the type of processing task the subject is performing: not all tasks tap the same strategy, although some tasks do suggest a preferred strategy.

The question how temporal relations are encoded is also addressed by Thomassen & Teulings (1985, chapter 17 of the present volume) and Shaffer (1985, chapter 15 of the present volume). They point out that time is not necessarily encoded directly at all in the highly overlearned skills they are studying. The fine and consistent timing that is required, for instance in writing or musical performance, is likely to be “a consequence of the smooth functioning of the physiological and biomechanical systems involved in the process” (Thomassen & Teulings, 1985, p. 000).

In summary it seems appropriate to accept the idea that time can be, but is not always directly encoded. Especially in overlearned, automatic skills like writing it is not. This strongly suggests that processing temporal information is indeed largely a deliberate cognitive activity, requiring a great deal of attention and strategic flexibility on the part of the individual. When and if temporal information is processed, order may be considered as the predominant stimulus attribute, but it is certainly not the only one. Other, intrinsically non-temporal cues may be given a (quasi-)temporal interpretation. This quality plays an essential role in my further discussion.

6 Models of Temporal Information Processing

6.1 Introduction

A number of theories has been proposed to account for temporal information processing, although not many have been generated within the confines of the information processing paradigm. It is one of the areas in which time psychology proper and cognitive psychology have not yet merged. The theories and models dealing with the encoding and storage of temporal cues can be subsumed under two labels first proposed by Michon (1967a, 1972) and Ornstein (1969), namely clock theories and event-related theories.

Clock theories are based on a general scheme in which a hypothetical internal time base generator is driven by some process of central activation (e.g. Treisman, 1963). The level of activation and, hence, the 'clock rate' is determined by the complexity of the external situation and by various physiological and psychological states, such as body temperature or anxiety. The time base emits (quasi-)periodic or random pulses which are then counted or integrated and thus provide the internal reference against which temporal behavior is performed. A detailed account of clock theories is found in Macar's chapter in the present volume (1985, chapter 7).

Since in this approach it is impossible to distinguish qualitatively between the various factors that may cause fluctuations in the rate of the internal clock, there has been a steady push towards the second type of theory which makes many more explicit allusions to the role played by the situation (number and complexity of events, contextual stability) and the individual (alertness, expertise, intoxication, etc.). Chapter 11 by Block (1985, see also Block, 1974), in this volume, presents a typical example of this approach, which dates back at least to Guyau (1890; see Michon & Jackson, 1984).

Clock theories and event-related theories both acknowledge the necessity of some internal time base, but the latter gain some flexibility since they explicitly avoid the unnecessary extra step of translating event-related states into a state of specific activation that is required in clock theories to account for the fact that a time base generator must somehow be driven. This step appears uninformative given the opportunistic choice of timing mechanism discussed earlier in this chapter.

6.2 A Generic Model

The insight that a theory of temporal information processing should be formulated in terms of event-related attributes rather than in terms of clocks or specific activation mechanisms should remind us of the fact that the independence of temporal information have already been claimed. A plausible theory should give an account of this independence. Furthermore, to the extent that temporal information processing is indeed an activity that is under attentional control rather than automatic, such a theory should also take into account that the attentional resources of human beings are limited and that, therefore, explicit temporal control must impede the control of propositional and spatial information.

In 1975 Thomas (Thomas & Brown, 1975; Thomas & Weaver, 1975) proposed a formal model of time estimation which meets these requirements. The model was presented as a summary description of a series of experiments on the perception of brief durations in the 100 ms range, but it was stated in such general terms that it can be transposed unconditionally to a much wider range of intervals (see also Macar, 1985, chapter 7 of the present volume). As such Thomas' model may be considered an important contribution to the theory of temporal information processing. The model can be summarized by the following functional equation,

$$t_{est} = \alpha f(t, I) + (1-\alpha) g^*(I, t)$$

stating that the judged duration of an interval is a weighted function (with parameter α) of the directly encoded temporal information $f(t,I)$, and the remembered temporal information $g^*(I,t)$. In terms of the theoretical position adopted so far in this chapter, directly encoded temporal information should be understood as the temporal cues that a person extracts from a time interval when and as long as it is in progress. Such cues will, as I argued before, mostly but not exclusively be derived from the order of events. Depending on the effort spent in processing temporal cues (t) while the interval lasts, there will be greater or less opportunity to pay attention to other, non-temporal attributes of the stimuli (I). Hence, depending on such factors as instruction, interest, or physiological state, a person can either obtain a good immediate estimate of the duration of the interval or a good encoding of the (non-temporal) content of the interval, but not both. If, on the other hand, a judgment about the duration of an interval is asked after some delay, the interval must first be remembered (that is, located in permanent memory). This involves a reconstruction (g^*) of the duration of this interval on the basis of its non-temporal contents (I) and the originally extracted temporal cues (t) in as far as the latter were at all encoded and stored in permanent memory. Dynamically, judgments about remembered duration depend on the initial division of attention between non-temporal information (I) and temporal information (t), and on the rates of forgetting both kinds of information. It may be assumed that propositional and spatial information, when encoded, will be retained very long in comparison to temporal information, which, supposedly, is extremely volatile. If a remembered interval is judged veridically, therefore, it must be by virtue of a consistent, detailed reconstruction of the non-temporal contents of the interval (from which subsequently a new temporal estimate can be derived). This dynamic balance between the abilities of judging time in passing and in retrospect is represented in Thomas' model by the weighting parameter. If $\alpha \rightarrow 1$, immediate judgment will be excellent (at least if the content of the interval does provide temporal cues at all) while judgment of remembered time will be poor. If, on the other hand $\alpha \rightarrow 0$, immediate judgment of duration has to be rudimentary while retrospectively the interval may be constructed adequately and a veridical temporal estimate derived from it.

Thomas' model offers a consistent summary of a large number of interrelated facets of temporal information processing. I shall refrain from a detailed discussion of these aspects, only to mention that the model provides an excellent vehicle for the description of 'flow', the subjective rate of time passing, one of the two attributes of time experience that were recognized as basic earlier in this chapter.

It is common experience that time periods which seem to pass quickly tend to become longer and longer in retrospect. An absorbing theater performance, an exciting holiday, or a romantic evening have a content (I), so absorbing that little or no attention remains for the temporal cues (t) that such events might in principle provide. The resulting immediate judgment therefore tends to severely underestimate the actual duration. In retrospect, however, the intense cognitive commitment must result in an overly detailed mental reconstruction of what happened during the original event. The density and the detail with which events have been experienced will generally provide a relatively high quota of temporal cues on which to base a retrospective judgment of the period involved. Immediate and retrospective judgments must therefore necessarily counterbalance each other. More dramatic even than a romantic evening is the near fatal accident. Accounts of people who were nearly killed in a car accident or falling down a precipice frequently amount to the paradoxical statement that it was all over before they really knew what was happening, while at the same time they had all the time in the world to take evasive action. The only way out of this paradox is to realize that the two observations refer, respectively, to immediate and retrospective experience of the duration of such events. We may assume a paroxysmal outburst of brain activity in the endangered organism during the event with no attention for temporal cues whatever, while at the same time generating a very high amount of non-temporal information.

6.3 Psychophysical Constraints on Temporal Information Processing

Although Thomas' model covers an important part of the temporal information processing territory, it is formulated as a qualitative model and one remains curious about the actual form of the functions f(t, I) and g*(I, t). The answer should be derived from the psychophysics of time, actually the oldest branch of time psychology and perhaps the most overworked. Macar (1985, chapter 7 of the present volume) provides a concise summary of the major results in this area. From the available evidence it can be concluded that, at least for the range of intervals that concerns us most—seconds to minutes—the psychophysical function connecting estimated and physical time is following the well known 'power law' of Plateau-Stevens (e.g. Stevens, 1975; Eisler, 1975): $t_{est} = at^b$. The various factors that may influence the actual judgment, viz. illness, alertness, or skill, apparently influence the value of both the parameters a (arbitrarily) and b $(0.5 \le b \le 1.0)$. This amounts to the conclusion that subjective estimates of time are proportional either to true physical time or to the square root of physical time, or somewhere in between, depending on the circumstances and the task imposed on the subject. Whatever the general shape of the psychophysical function, from the variability of its parameters it should be evident that there is more to time judgments than meets the eye. I shall briefly mention four factors with a quite conspicuous influence on the empirical results.

6.3.1 Volatile Time Constants

The literature on temporal factors in behavior has made us familiar with several time constants that appear to play an important role in the temporal control of behavior. The more prominent among these are the time quantum (for which values between 25 and 100 ms are reported), iconic storage (300 ms), the indifference interval (400-700 ms), the psychological refractory period (initially 250 ms), primary memory (3-5 s), and the range of short-term memory (20-30 s). Some of these mechanisms are discussed in some detail in later chapters of this book.

It is my contention that such time constants will be found operative only in extreme conditions, namely in laboratory experiments and in other unfamiliar conditions in which the subject has no finely tuned temporal response strategies or schemata available and is thrown back on his or her basic processing mechanisms. As soon as more sophisticated task performance is required these time constants stop being constant and take on values that reflect the properties of the task rather than those of the organism. This point is illustrated for instance in the distinction drawn by Jones (1985, chapter 13 of the present volume) between 'rate relational pattern perception' and 'coding'.

6.3.2 The time quantum

The time quantum being set initially at roughly 100 ms,has moved to 50 and later even 25 ms, assuming every conceivable value in the meantime as a consequence of task variables (Michon, 1967a), training variables (Kristofferson, 1976), or structural variables (Warren, 1974). Another fish in the same kettle is the so called psychological refractory period, a very popular research topic in the 1960s. The idea is that upon presentation of a stimulus the processing of that stimulus will absorb the internal processing capacity to such an extent that subsequent information must wait until some capacity becomes available. At one time it was thought that this period was of the order of 250 ms. Then, when data from a wider range of situations became available, it turned out that the 250 ms range was too restricted and other estimates started to appear, until it was decided that the psychological refractory period would easily assume any value between 0 ms and 700 ms, depending only on the nature of the task (Kahneman, 1973).

6.3.3 Time constants and opportunism

In summary, although the organism may display certain time constants when brought under extreme task conditions, in most actual situations the evidence for the constancy of such constants disappears and their values appear to be determined only by the requirements imposed on the organism by the task it is performing at the time. It will be evident that this brings us close to what was said in an earlier section about the opportunistic character of the choice of an internal time base.

6.3.4 *Linearization of Time*

The exponent b in the power relation between estimated and physical time, $t_{est} = at^b$, takes on values between 0.5 and 1.0. Eisler (1976), in a heroic compilation of no less than 112 experimental studies, established that in more than one half of these studies there is a simple linear relation between estimated and physical time. As Michon & Jackson (1985, chapter 1 in the present volume) point out, Paul Fraisse had, already in 1957, reached the conclusion that the best subjective measure for the second is the physical second. Yet, even though one half of the studies support this view, the other half apparently does not, and the question may be raised what is the matter with that second half. In a study reported some time ago (Michon, 1975), I have suggested that there may be two essentially different ways of representing the psychophysical scale of duration, an 'analytic', linear scale consistent with Fraisse's contention, the other an 'impressionistic' scale in which estimated duration varies with the square root of physical time. (The intermediate values of the exponent b should, perhaps, be considered as artifacts from averaging over subjects or as the result of mixed strategies). The impressionistic scale was found over a considerable range of intervals in young children, gradually disappearing with increasing age (Fraisse, 1948); for intervals longer than 20 s in people with defective memory (Richards, 1973); and in some normal subjects (Clausen, 1950). Furthermore it is normally found for intervals shorter than about half a second (Michon, 1967b).

In summary, adult subjects will always represent time in a linear fashion between 0.5 and 20 s. Both shorter and longer intervals may, however, be represented proportional to the square root of physical time.

These findings suggest an immediate relation to the tuning function of temporal information processing. As I argued before, tuning requires a near perfect correspondence between external and internal events. Such a relation can only be achieved when the internal events run off in 'real time'. Consequently the internal time scale must be linearized over a considerable range in order to make adequate tuning possible. The range between 0.5 and 20 s, being roughly the lower and upper bound of working memory, would serve this purpose perfectly well. This range may be seen as representing the variable temporal window that interfaces us with reality, probably with a lower limit, an 'idling value', of 0.5 s, but longer when the input permits. Below 0.5 s information processing is of a highly perceptual nature, fast, parallel and not accessible to cognitive control. Accordingly temporal information could well follow the 'impressionistic' square root scale in this 'ultrashort' range. At the upper end, beyond 20 s most adults will by and large, but not always, linearize their time scales with the help of clocks and calendars and with a great deal of prior experience in linearizing time. If, however, anchoring points are not available, because long-term memory cannot be accessed in a conventional way for some reason, the impressionistic mode may take over. Only children may have difficulty in linearizing the interval over which working memory is operating; that is why children are so very apt to make timing errors until they are between 8 and 10 years of age.

6.3.5 Partial Order and Hierarchical Organization

A third aspect that deserves brief mention is that it has gradually become clear that temporal information is not necessarily encoded and stored in a simple serial fashion. Although duration is frequently represented as a one-dimensional scale, it is evident that most people do not normally represent their experiences on a fully integrated, single time scale.

On the macroscopic scale of one's personal history there would seem to be at least several more or less independent times, one for each of the major areas of activity; family life, work, community activities, and the public arena as it is reflected in the news media. Connecting these times into one global time scale may be quite difficult and exceed people's cognitive capacity.

At the microlevel it is the phenomenon of perceptual streaming which establishes the fragility of the one-dimensional representation of time. Streaming involves the separation of events from a single sequence of tones into two (or more) independent sequences. The best known example is a melody which breaks into two separate 'voices' when high and low tones are rapidly alternating. Composers use this phenomenon, especially in their pieces for unaccompanied solo instrument. Between streams no temporal relation can be established: the order of specific tones in two streaming melodies cannot be determined relative to each other. The indeterminacy of temporal relations resulting from streaming can only be solved indirectly if the listener succeeds in establishing a temporal hierarchy among the various 'voices' or parts of an event sequence. Hierarchies have been observed in rhythmic keytapping performance (Vorberg & Hambuch, 1978, 1984), and in short-term memory (Estes, 1972; Lee & Estes, 1977, 1981; see also Estes, 1985, chapter 10 of the present volume). Functionally they are of great importance because a hierarchical organization allows the person to incorporate more complicated higher order relations into the way he or she encodes temporal information. As a result longer and more complex event sequences can be coped with and accordingly the tuning process is facilitated. Hierarchical organization plays an important role- in the construction of the experienced present, as will be explained later.

6.3.6 Perturbation

Temporal information appears to be very instable, and although it may initially be encoded veridically, forgetting may be very quick. Apparently, however, this does not always happen, which indicates that at least the normal adult person has the means available to compensate for the loss of temporal information when estimating time. Yet, under certain conditions the instability of temporal cues becomes noticeable.

This phenomenon has been studied by Estes (1972, 1985, chapter 10 of the present volume; see also Lee & Estes, 1977, 1981). Estes addressed the issue how the position information of items in a memorized list of letters or words becomes less and less certain over time. By assuming that the initial temporal positions of the items are increasingly perturbed since they are subject to stochastic fluctuations, he was able to give a temporal interpretation of inversions between items, intrusions from other lists and total forgetting of some items. Estes' model supposes that each item's position is subject to a two-directional random walk, a model that is similar to a model proposed by Michon (1967a) to explain irregularities in tapping behavior. Perturbation may account for the quick loss of temporal information revealed by psychophysical studies. It may also account, therefore, for the square root relation that, as I pointed out, is occasionally found between estimated and physical duration. A square root relation is actually what one expects on the assumption that the perturbation process has indeed the characteristics of a simple stochastic random walk: in such cases the variance of the estimated length of the interval between two points t1, and t2 will vary with the difference (t2 - t1).

More importantly than its ability to explain the loss of temporal information is the fact that the perturbation mechanism confronts us with the limits of the functional information processing approach that I have outlined above. The reason is that with increasing length of retention perturbation would exceed all bounds, and our memories would collapse in chaos. Nothing in the process would seem to stop the loss of information. Yet this is not what we see happen and we must therefore conclude that the structural properties of event sequences contribute in a fundamental way to the coding, storage and retrieval of temporal information.

7 The Structure of Temporal Information

7.1 Patterns

If we study how people organize their memories it is clear that the processing and retention of temporal information is dependent on the pattern of the input information. Estes (1985, chapter 10 of the present volume) does also hint to this when he suggests that temporal factors in memory should be studied by introducing complexly organized stimuli such as sentences, since "language introduces structures in a hierarchy that constrain perturbation models in meaningful ways".

In this context it is necessary to distinguish between patterns and codes. A pattern can be defined as a codable array of entities (symbols or events, for instance numbers), while a code is a set of rules that describe patterns in such a way that the code is finite and more compact than the original series. If an array (e.g. a string) cannot be represented in a compact way in any conceivable code it does not count as a pattern; this is the case, for instance, with the decimal fraction of the number pi = 3.1415926535..., whereas the decimal fraction of 1/7 = 0.142857142857... represents a very simple repeating pattern with a period of 6 places.

A second basic distinction to be made when we discuss patterns and codes is that between sequential patterns and temporal patterns. The former category is specified only in terms of the order between elements of the sequence, and clearly represents the sort of temporal strings that are supposed to lie at the heart of the representation of temporal information in memory (see above, and Anderson, 1983). Temporal patterns in the proper sense are sequential patterns in which additional (absolute or relative) temporal relations are specified. Musical patterns and more specifically rhythmic patterns, which encode (relative) duration, belong to this category.

The question is how the information processing system does cope with the syntactic structure of these patterns. Considerable attention has been given to this question in the past fifteen years. Several of the chapters of the present volume deal with this matter, particularly Jones (1985, chapter 13), Povel (1985, chapter 14), Shaffer (1985, chapter 15), and to some extent Nooteboom (1985, chapter 16) and Thomassen & Teulings (1985, chapter 17). Rather than summarizing the findings these authors will discuss in great detail, I shall only refer to a few fundamental aspects that are inherent in this approach to temporal information processing.

A first point to mention explicitly is the important distinction drawn by Jones between—what she calls—rate relational and coding theories. This is an important distinction because it focuses on the difference between the approach in which the internal processing stages are considered as the central features of psychological theory—an approach that is commonly known as 'performance theory'—and the approach that is more concerned with the intrinsic structure, the 'affordances' (Gibson, 1979), of the information presented to the subject. Coding theory deals with 'competence' rather than with performance. The polarity between competence and performance, which originated in the once heated discussion between linguists and psycholinguists (see e.g. Lachman et al., 1979), turns up in various other disguises elsewhere in psychology. There is a general trend in the development of information processing theories in which a particular phenomenon is initially described in terms of an internal, frequently neurophysiological, mechanism. When the search for such a brain mechanism is found to be fruitless, and it usually is, the next stage is a functional description in terms of processing 'stages'. Subsequently these 'stages' tend to become formulated less and less in terms of generic performance terms, such as 'encoding' or 'response selection' and instead they begin to mimic the structural features of the stimulus domain or domains to which they apply. The processing mechanisms seem to leave the body (and the mind) to become structural 'affordances' of the environment (Michon, 1984). Herbert A. Simon (1969, p. 24) epitomized the latter stance when he contemplated the complex behavior of an ant on the beach: “An ant, viewed as a behaving system, is quite simple. The apparent complexity of its behavior over time is largely a reflection of the complexity of the environment in which it finds itself”. This trend from mechanism to contextualism (de Mey, 1982; Michon, 1984) appears in a number of ways also in Time, Mind, and Behavior: time psychology is apparently taking part in this general trend, the same trend, incidentally, which I earlier in this chapter diagnosed in physics (with reference to Park, 1985, chapter 3 of the present volume) as the attempt to eliminate the observer from the cosmos and to denounce the reality of time.

7.2 Pattern 'Extraction'

The importance of context in contemporary psychological theory is a product of early applications of statistical information theory to psychological problems. Shannon's theory gave psychologists the insight that the meaning and significance of a stimulus cannot be determined in an absolute sense, but only relative to the set of stimuli to which it belongs. This was borne out most explicitly by Garner (1962, 1974) who, moreover, underscored the psychological significance of what he called 'structural uncertainty' (vs. event uncertainty) with a battery of supporting evidence. One revealing phenomenon is colloquially known as 'motorboating'. It pertains to our ability to perceive the periodic character of a cyclically repeated burst of pure stochastic noise. Although the whole sequence of such bursts is, technically speaking, locally strictly random, people easily extract the hidden autocorrelation and as a result they tend to report a stable perceptual impression, a sound more or less similar to the chugging or throbbing of a ship's engine.

Garner and his associates studied cyclical patterns of high and low tones in order to find out what the structural features of such patterns are that determine the organization of a stable perception (Garner, 1974; see also Jones, 1985, chapter 13 of the present volume). They found two features that largely determine the stability of a cyclical tone pattern: the length of a subsequence that constitutes a 'gap' or pause at the end of one cycle and the length of a subsequence of tones that constitutes the starting 'run' of a cycle. Ambiguity will result from a conflict between the two features or from the absence of a sufficiently long and therefore dominant 'gap' or 'run'. Garner's research, leading to the ultimate conclusion that stable and perceptually 'simple' patterns are those that have a unique description in a given code, has triggered an avalanche of research in an area now known as structural information theory. Jones, in her contribution to the present volume, has outlined the development and the major issues in this fertile domain in as far as they are relevant to the encoding and retention of temporal patterns.

7.3 Meaningful Patterns

As I have argued, the encoding of temporal information relies on a mixture of cues: order, causal, spatial, and conventional. The question is in what conceptual structure or structures these cues are eventually imbedded. The authors of the chapters in Part IV of this volume (chapter 18 by van Benthem (1985), chapter 19 by Montangero (1985) and chapter 20 by Michon (1985b)) are all concerned in one way or another with just this problem. They make it clear that the classical conceptualization of time as a simple spatial metaphor—an arrow passing from back to front through the body of the person—cannot be maintained.

Van Benthem (1985), for instance, stresses the pluriformity of the formal 'mathematical ontologies' from which various conceptualizations can be derived, such as, for example, point logic and interval logic. Even though formally the two can be derived from each other, the psychological consequences of a point logic versus an interval logic are quite different. Van Benthem goes even as far as to suggest that the interval representation lies at the root of individual time while the point representation is a cognitive construction, that is characteristic of public time.

It is a long way from a 'mathematical ontology' of time representation to a concrete conceptualization. A psychologically important step in that direction was taken by Miller & Johnson-Laird (1976) in their classic book on perception and language in which they developed their ideas of 'procedural semantics'. Procedural semantics implies that words and sentences serve as prescriptions that tune the organism to certain perceptual or cognitive conditions. People have a sharply tuned ability to decide which temporal relations in a set of verbal assertions are consistent and which are not. Whether a certain temporal expression is accepted as a valid description of a given situation or event depends, according to these authors, on implicit checks about the truth-table values of the constituent elements of the expression. Thus, the sentence “The shop was closed as long as the bomb exploded” is considered incorrect because the expression “as long as” requires a durative proposition on either side; and usually the explosion of a bomb is an instantaneous event. Recent progress towards more sophisticated conceptualizations of time has been made by Allen (Note 1; 1983), who developed a formalism for describing temporal structure on the basis of what the state of the world is before and after a certain event rather than describing the changes during the actual transition. His approach allows the full advantage of the interval logic described by van Benthem (1985, chapter 18 of the present volume).

7.4 The Construction of the Present

The experience of now, classically known as the specious present, has been considered from several points of view. Some authors (reviewed by Macar, 1985, chapter 7 of the present volume) have chosen the minimum option of the threshold of order perception (20-200 ms) as the possible range for the experience of now. Others, including Mandler (1975), Jones (1976), Michon (1978), and Kunst (1978) have taken a much more dynamic view. This view is actually one that is conceptually consistent with the classical view of the present (represented in the work of e.g. Wundt, and James; see Fraisse, 1957, for an overview), but also with much of the work on incremental models of speech understanding and speech production (see e.g. Kempen & Hoenkamp, in press). The basic idea is that the experiential present is initiated at a certain instant, when a sequential pattern of events is beginning to be presented to a subject. On the basis of the first, minimal cues an interpretive context is generated and on that basis a hypothesis (representation) is formed about the future possible course of events. This process of generation and confirmation should actually be seen as the warp and woof of the tuning 'window' that inferfaces the subject with reality in real time. If, and as long as the anticipatory hypothesis is confirmed by what is happening in the outer world, the 'window' can expand and accordingly the experience of now becomes more extended (Mandler, 1975). If the hypothesis is not borne out sufficiently well by subsequent events, a new anticipatory hypothesis may be selected within the selected interpretive context and tested by backtracking. If this does not meet with success, the chosen interpretation has apparently no further merit and must be replaced. At that point the current now is interrupted (segmented), its contents thus far—up to the point where no extrapolation to new events turned out to be feasible—are transformed, from the surface level (at which temporal information is generally encoded) into a deep-level representation, and a new interpretive cycle is started. This idea implies that past or remembered time has a discrete structure and can be represented by strings of (meaningful) chunks that are derived from a highly interactive interpretive tuning process. Although such a view of the now as the product of the tuning process is still in its infancy, it seems capable of incorporating many aspects of the information processing approach and the coding approach outlined in the preceding sections.

8 Selforganization and the Reconciliation of Structure and Function

Structuralistic theories impose their own problems that ultimately disqualify them as psychological theory. If a purely linguistic approach to language eliminates the need for a speaker or a listener, and if geometrical optics is, after all, a theory of visual perception without a perceiver, what would be the merit of a theory or temporal coding as a theory of time experience? There would be no such merit, but at the same time it appears impossible to go very far in that direction. Once more it seems impossible to eliminate the observer from the universe. It has been pointed out that patterns—which include sequential and temporal patterns—are patterns by virtue of the structural context in which they appear. A wedge-shaped symbol V will be different if it is an element of the set {U, V, W, X}, than if it belongs to the set {~, V, &, ->}. The question that structural theories have always great difficulty in answering is what, or who, determines that context. This difficulty is a matter of considerable dispute in contemporary cognitive psychology and philosophy of mind and therefore, to find it discussed in several of the chapters of Time, Mind, and Behavior is indicative of the timeliness of the book.

Structures, described variously as formal theories, axiomatic theories, mathematical ontologies, etc. are related to a representational mode (or grammar)—propositional, imaginal or temporal—which is the vehicle for conceptualization, through an interpretation function, a “systematic 'recipe' between grammar and mathematical ontology” (van Benthem, 1985, chapter 18 of the present volume). Point logic and interval logic are examples of such interpretation functions: they specify very different and independent ways of representing temporal relations, and as such they offer independent but not quite unique views of the temporal structure of reality.

This view, however, remains incomplete and arbitrary as long as it is not made clear why some structures appear to invite a certain interpretation rather than another one. In Goodman's (1984) terminology: “humankind makes versions of the world, and true versions make worlds”. But, how do we know which versions, which of our representations are indeed true. In several chapters the authors hint to this crucial question. Thus, Shaffer (1985, chapter 15 of the present volume) points to the fact that the quality of sight performance of musicians suggests that there is a certain necessity to musical pattern. And similarly both Jones (1985, chapter 13 of the present volume) and Povel (1985, chapter 14) appeal to the fact that temporal structures may derive their “appropriate interpretation” and their functional significance from their temporal (rhythmic) aspects.

9 Summary and Epilogue: What Is It Like to Build a Time Experiencer?

In retrospect we can conclude that time psychology has come a long way to becoming a respectable concern for psychologists. The realization that time is a manifestation of the need to exchange information with the environment to enable an organism to stay geared to the course of events in its environment has triggered a substantial and substantive amount of research in the field. Let me summarize the basic task of time psychology stated in the Prologue by considering what would be needed to build a special version of the 'compleat time experiencer' we have been looking for, namely a robot that would be temporally as independent of its working environment as humans are of theirs. Like humans, robots are operating more or less independently of their environment. Machines have, of course, been known to do jobs under extreme conditions, in heat, cold, poisonous or other adverse circumstances. Classically that does not involve structural adaptation: the structure of a machine normally does not change as a function of the environmental circumstances. Living organisms, however, do have that potential. Even primitive species have managed to cope with variable circumstances. The most fascinating development of this kind has been the 'programmable memory', that allowed each individual of a species to learn and benefit from its own private experience. One concomitant of this development was the emergence of symbolic representations that allowed anticipation and advance evaluation of behavioral options. In higher organisms this independence implies temporal independence, both with respect to periodic and singular, progressive processes. This involves tuning to the events occurring in reality. Although clocks may be involved, these clocks require constant tuning and retuning. A robot that is to function truly independently of its environment should enjoy the same temporal independence of the external course of events as people. That is, it should need no time bases that are permanently synchronized with an external clock (although resetting once every day should probably be allowed). For the rest the robot's action should depend only on the representation of what is required by the prevailing circumstances, and on the basis of past experience and future goals. This requires an elaborate representation of time that should allow both overlearned activity sequences to run off more or less uncontrolled in a data-driven fashion and an elaborate 'top down' repertoire of cognitive strategies for coping with temporal contingencies that require planning, reflection and communication.

It appears that important progress has been made in the direction of a functional model of time, that is, the design of a model that can explain observed behavioral patterns and subjective phenomenology in terms of underlying processes: biological rhythms, constraints on working memory, thresholds for differences in stimulation, to name a few. Most of these models appear to have used the clock concept in one way or another. I have also considered the need for a complementary approach, based on the idea of structural information theory: not only order is given in nature, but certain other temporal relations are also contained in the events that occur in the organism's environment. Rhythmicity, recurrence, etc. are not simply imposed on event sequences by the organism but are 'afforded' by the structure of the environment. The question is how these 'affordances' are picked up.

Evaluating both ways of coping with temporal experience while avoiding intentionalistic explanations, a fundamental problem has come under consideration in recent years. It is important to mention that this topic is dealt with by several contributors to Time, Mind, and Behavior. This clear trend in cognitive theory, concerns self organization as a crucial step in uniting the functional (performance) and structural (competence) approach to information processing. Wonham's (1976) principle, Prigogine's (1980) 'dissipative structures' which maintain their internal structure while interacting with their environment, and J.J. Gibson's (1979) 'affordances' are complemented, in a fundamental way, by Jones' 'dynamic serial transformations', van Benthem's 'systematic recipe' for interpreting formal 'mathematical ontologies' in terms of (natural) language, Michon's reference to 'generative metaphor', and by Park's plea for a conscious 'observer' in physical theory. They all imply the deep-felt desire to cope, in information processing theories, with structure and function at the same time (e.g. Goodwin, 1983; Michon, 1984). Uttal (1978) has phrased this desire in terms of the relation between a wheel and its rotation: we are faced with the functional question how a wheel generates rotation and with the complementary structural question why precisely rotation is the 'natural' or 'self-evident' product of a wheel. Within the present context of Time, Mind, and Behavior all these recent efforts aim at answering one paramount question: How does an event sequence evoke in the observer a certain interpretation of context in which the sequence occurs, such that the result is a stable representation of that sequence, that is a pattern. Stable representations in this sense are a necessary requisite for adequate tuning performance. But adequate tuning performance is in turn dependent on the interpretation of the dynamic features of the external situation. Like wheels we appear to go round in circles: let us hope that they will not be vicious circles.

Dealing with such a dynamic concept of internal structure requires a formalism, a metamodel if you like, from which any representation of time, and thus any functional basis for time experience, can be derived through a choice of interpretation. Only when such a metamodel will be available it will become possible to decide unambiguously whether indeed time is a unitary concept, or perhaps a multiplicity depending on an inhomogeneous set of explanatory concepts. As yet the matter is undecided.

10 References

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