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On the Modularity of Time[1]

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Abstract

Instead of referring to time as an external chronometric reference, the relational approach to time is based on the concept of multiple time encodings: times are the intrinsic products of dynamic representations of the world around us. Such time encodings have in common that they provide a cognitive anchoring for the way we perceive or represent certain systematic aspects of reality. For most systems a time encoding can be derived that will minimize the complexity of describing the dynamics involved. The human capability of coping with change relies on both evolved (innate) and learned mechanisms and strategies that can detect such 'minimal' system representations. The examples discussed in the text were taken from a wide range of disciplines. This suggests that the concept of local, relativistic representations of time plays a distinct role in scientific explanation. In recent years this conceptualization of time is seen to gaining importance.

Introduction

Tuning, the temporal adaptation to the contingencies of a changing environment is a must for living creatures to remain functionally intact. In primitive organisms such temporal adaptations are rigidly predetermined by the system's architecture, even though they may be adaptive in a limited sense. With the evolution of a specialized nervous system, each exemplar of a species became capable to learn and benefit from its experiences, thereby considerably enhancing its chances of survival. A well-developed central nervous provides independence from the environment with respect to both periodic and unique temporal events. The temporal control of complex behavior as we find it in humans relies on dynamic representations, partly innate and partly acquired. By applying representations of the temporal structure of events—frequently referred to as 'scenario's or 'scripts', following Schank and Abelson (1977)—we are able to understand and use the behavioral and cognitive coherence of episodes of real world events.

It is the aim of chronopsychology—the psychology of time, one of the most ancient branches of experimental psychology—to establish, in the first place how the mind/brain is able to cope with the temporal contingencies of this dynamic world, and in the second place how this coping effort can produce the many and varied ways in which people experience time. Some characteristics of subjective time seem to be universal, such as the experience of the present, the subjective flow of time, and the distinction between past and future. Subjective time may, however, also involve less common and even pathological features. This includes the apparent halting of time that is common in depressive patients, and the more excessive forms of *déjà-vu* that accompany certain organic brain diseases.

Our experience of time is much more complex than one would expect on the basis of the structure of space-time as it figures in contemporary physics (Sklar, 1974).This does not necessarily mean that the human mind is adding a good deal of irrelevant detail. Rather, in my view, the picture of physical time as it has developed since the middle of the 18th century presents an incomplete and impoverished view of the dynamic nature of time. Philosophers are split on the issue. Some have declared time unreal, a logical or psychological artifact of the way we think. Others consider it real and a fundamental feature of reality. Some hold that it is based on the idea of *being* and there are others who think of it dynamically in terms of *becoming*. Finally there are those who take time as an absolute, external reference and others who feel that time derives from the relations between successive events. On balance it appears that the flow of time is indeed an inherent property of the events that take place in the physical world, but that to recognize this property a conscious observer, tuned by evolution to the dynamic characteristics of this reality, is needed (Michon, 1985a). A similar conclusion was reached, for instance, by Prigogine (1980), according to whom the fundamental character of time is evidenced by the existence of (human) observers who are capable of distinguishing between the past and future directions of time. From what they observe, the concepts of dynamics can be derived which, in turn, lead to the concept of time irreversibility (as in thermodynamics). However, as Prigogine points out, an additional step is needed, forced by recent studies of the time-asymmetric behavior of systems—such as humans—that operate far from thermodynamic equilibrium. The behavior of these systems, called *dissipative* because they exchange energy with their environment, rests upon a fundamental break of time symmetry which turns the irreversibility of time flow into a law of nature, independent of the observer. Ultimately, however, this reflects back onto the (human) observer so that “we can now recognize ourselves as a kind of evolved form of dissipative structure and justify in an ‘objective’ way the distinction between the future and the past that was introduced at the start” (Prigogine, 1980, p. 213).

This position introduces the familiar framework of scientific realism. We can now proceed by assuming that the temporal structure of events is indeed physically grounded. As a psychologist I wish to establish how such real-world event structures are *perceived*, *represented* and *applied,* what mechanisms are involved in the process, and how they can generate the rich variety of temporal phenomena of which we are normally aware?

Modularity

In this article I shall review the role and use of various representations of time, each of which can help human beings, *qua* cognitive system, to cope with specific aspects of a changing world. In this context I take the view that the variety of temporal experiences reveal an underlying structure that we may characterize as *modular*. Cognitive psychology, as it has developed over the past fifty years, has revealed a substantial number of specific mechanisms, processes and strategies. Mental activity has been shown to have a rather involved modular basis. To speak of the 'modularity of mind' (Fodor, 1983) means to recognize the presence of highly specialized functions that do, among other things, warn the organism for a the presence of a cliff it could fall off, streaming water it could drown in, or an approaching predator it might be attacked by. Characteristically such modular functions are highly specialized. That is, they can do only one thing but they can do it very reliably and fast. Usually the actor will not even be aware of the activity of these modules. Also it is practically impossible to modify their output. In recent years evolutionary psychology has come of age and the human mind/brain is now seen as the result of a long evolutionary process of functional adaptation to an increasingly complicated environment (Barkow, Cosmides, & Tooby, 1992). In humans, however, even the most basic cognitive mechanisms and functions need not be ready for use at birth. Human beings go through a protracted period of (more or less spontaneous) development and are, in addition, capable of extensive learning.

The force of time can already been observed in infants soon after birth. There is even evidence that the fetus is affected by the heartbeat of the mother during pregnancy. Temporal relations apparently contain information, and both humans and animals use this information to guide their behavior as soon as their developmental state allows them to do so. The question is therefore whether we may assume that temporal relations are explicitly represented in the mind/brain and that we have indeed at our disposal a variety of modules—*sensu* Fodor (1983)—for coping with specific, biopsychologically meaningful classes of temporal information. I put this position originally forward in what has become known as the *equivalence postulate* (Michon, 1972). This does not necessarily mean, however, that this temporal information must be encoded directly. For example, in their ground-breaking discussion of 'procedural semantics' Miller and Johnson-Laird (1976) argued convincingly that words and sentences serve as prescriptions for tuning the perceptual mechanisms of the organism to certain input conditions. Thus, hearing the word *red* will activate one's readiness to pay attention to red stimuli in one's visual field. But, whilst there are perception-based tuning mechanisms for such dimensions as color or shape, there appear to be no comparable mechanisms for temporal stimuli. Instead, the temporal relations expressed in the (English) language seem to reveal a propositional encoding based on some form of first order logic (Miller & Johnson-Laird, 1976, pp. 410-467).

The claim I wish to make in this article is a relativistic one. Temporal stimuli (instants and durations) are not directly encoded. Instead we are dealing with representations that encode the dynamic properties of events and episodes that are taking place in the real world, in such a way that we can remember them or act upon them. Such encodings describe the appropriate characteristics of local or episodic time *indirectly*.

Representations: implicit and explicit

In the first place we need to make a distinction between implicit and explicit representations. Implicit representations are abstract models for describing information processing. What we can say about implicit representations is inferred from the subject's behavior and need not reflect any specific mental representation. Such implicit representations are frequently subsumed under the heading of 'automatic processing'. Explicit representations, on the other hand, refer to mental representations of which the subject is consciously aware and that are cognitively accessible and modifiable. The features of implicit temporal representations have been described in a variety of computational theories and models. Prominent examples are models of *natural computation* (as inspired by Marr, 1982; see also Richards, 1988), *naive physics* (Hayes, 1978, 1985), *dynamic attending* (Jones & Boltz, 1989; Boltz, 1993), *dynamic affordances* (Freyd, 1987, 1992), and *process-history recovery* as envisioned by (Leyton, 1992). A model of natural computation may, for instance, specify what in a dynamic visual scene gives us the impression that we are looking at a wildly streaming water surface (Kung & Richards, 1988), whilst Freyd's work on dynamic affordances and Leyton's analysis of asymmetry help us to understand why the 'frozen' image—a photograph, say—of a windswept tree reveals a great deal of the past history of that tree, and perhaps even what is going to happen to it in the near future.

Representations of time come in three varieties, which I have called *literal*, *figurative* and *formal*, respectively (Michon, 1990). At the first level concrete episodes (Tulving, 1983) and generalized episodes or scripts (Schank & Abelson, 1977) underlie the temporal organization of experienced events. When no suitable episodes or scripts are available to encode a particular experience, people will be forced to turn to the figurative level, that is, the level of analogies or metaphors (Lakoff & Johnson, 1980; Carbonell, 1982). Finally, in some cases they may rely on formal representations that have attained the status of scientific theories that may even be accepted as “true” representations of the real world.

EPISODES

Events in everyday life are encoded in a literal or verisimilar way, although in encoded form they may lose detail and acquire a schematic or prototypical character. In the course of their development humans build a repertoire of *scenario’s* (Schank & Abelson, 1977). Each of these scenario’s carries an implicit temporal structure that will tell us if the actual episode is unfolding in a dynamically plausible way. A course of events that deviates from such a ‘default’ scenario is quickly noticed and may be remembered quite explicitly and in great detail. In other words, humans are quick in picking up a repertoire of elementary temporal structures, and equally quick in using these elements to build an explicit representation of what is going on. The well-known experience of time passing too slowly or too quickly is caused, on this account, not so much by the number and complexity of events, but by these events experienced in their proper episodic context. Episodes encoded in this verisimilar way can be subjected to cognitive manipulations, including fast motion and slow motion, zooming, flashback, and flash-forward (‘what if’ hypothesis testing).

METAPHORS OF TIME

The structure and function of metaphor has been studied in great detail. Carbonell (1982) and, along similar lines Schank (1986) have provided us with process models of the stepwise matching process that will fit a metaphorical *source* (e.g., money) to its *target* (e.g., time). These models have been formalized to a degree that they may serve as a basis for an understanding of the analogical or metaphorical representation of temporal relations (e.g. Carbonell, 1985). When first confronted with a metaphor to describe a situation someone will attempt a literal reading. If this attempt fails, a further reading will be tried in terms of generalized metaphors (Lakoff & Johnson, 1980). If a suitable metaphor is found, the elements of the target situation are mapped into the semantic structure of the metaphor, as far as the interpretation will carry. The resulting interpretation may then be stored for later use in context. Thus, the expression *Time is money* will fail on a literal interpretation but it will succeed in generalizing the concept money to *valuable commodity*. If some fit is obtained a metaphor will generate further, related connected propositions: thus, it should mean something to borrow, waste, squander, or save time.

Among the so-called core metaphors distinguished by Lakoff and Johnson we may distinguish a small number that appear to accommodate temporal relations with particular ease. This includes not only time as space, but also time as a force of destruction as well as of growth and healing, time as flow, as a person, and as a valuable commodity (see Table 1 for examples).

FORMAL REPRESENTATIONS OF TIME

The philosopher Nelson Goodman succinctly summarized the problem of establishing an appropriate representation of the world around us: "People make visions and true visions make worlds" (Goodman, 1984, p. 34). Of all our attempts to construct representations of reality only a few are strong enough to support a coherent, generative view of the world in which all bits and pieces fit together structurally and functionally. Goodman's worlds should, of course, generate appropriate temporal representations too. Actually some of these have proved so successful that they have led us to believe that they tell us something essential about nature.

Table 1 - Some metaphors of time

CONTAINER
- the *corridors* of time
- habit *fills up* time

FORCE
- time *cracks* in *furious* flower
- time, *devourer* of all things
- time *cancels* young pain

RESTRAINT
- the bird of time *has little way*
- time made me his *numbering clock*

FLOW
- time is *flying*, never to return
- the *ever flowing stream* of time

PERSON
- time, the old bald *cheater*
- *daughters* of time

VALUABLE COMMODITY
- she lives on *borrowed* time
- time is *money*

Case-based time experience

The question we are facing concerns the relation between the 'local', episodic character of time experience and the abstract mathematical representation of time, the time of the physical clock that, in Newton's formula, "of itself, and from its own nature, flows equably without relation to anything external…" and that, subsequently, has shown itself to be accessible for advanced formalization. This Newtonian concept of time allows an unambiguous matching of any event with a single, external and totally independent reference scale stretching from minus infinity to plus infinity.

But, not all is well with this representation. According to Leibniz, the first to squarely attack the concept of absolute time, the dynamic basis of time derives from the relations between events: events do not simply occur in time, they constitute time. The concept of time as *deriving* from the relations between events has long been suppressed by the simpler and highly effective concept of linear, absolute time. It never disappeared, however, and one may trace its history from Leibniz to William James and beyond:

For James, nature has times, but no one time. An important implication of this viewpoint is that there can be no such thing as nature at an instant. The decline of one natural process to its final stage may well parallel the ascent of another process to its zenith… James simply denied that there was a single, master time flow in relation to which an invariant system of cross-references could be exhibited. Nature proceeded organically and not additively… Real time, James believed, comes in drops and not in fixed, quantitative increments. (Helm, 1985, p. 41).

From there we arrive at such recent concepts as 'episodic memory' (Tulving, 1983), 'implicit memory' (Schacter, 1996), the clausal structure of language (e.g., Pinker, 1994), and some of the findings of 'naive physics' (Hobbs & Moore, 1985) which seem to suggest that, psychologically speaking, local times are the rule rather than the exception.

In contemporary society we learn to organize our activities by the clock (as a *simile* for absolute reference time). Yet we continue to live by our episodic, contextual, experiences and as a result we observe time as going at some rate—flying or dragging. The implication of this relational view is that events and our experience of them generate their own homogenous local time. Ordinarily this intrinsic temporality will succeed in organizing the event as a coherent episode. Only if required by the task at hand, external clock time will be relied upon, for instance when episodes must be related to one another or explained to others, or if one is brought to a psychological laboratory to press buttons at regular intervals with the instruction not to think of anything in particular. Such activities will require special skills that, relative to physical time, rely on the precision of the 'internal clock'.

The relational nature of time implies that the popular assumption of a generic 'internal clock' is untenable. Instead one should turn to the form and content of the dynamic environment in which the behavior under concern is imbedded. This perspective invites two comments though. The first is that if all physical clocks and temporal switches derive their dynamic characteristic from the relational structure of ensembles of events, the aggregated output of each ensemble may still display the characteristics of a generic timer—or perhaps the term *virtual clock* is better. Thus the scalar timer proposed by Gibbon (1991, 1992) and others, including Killeen & Weiss (1987) and (Wearden, 1991, 1992), may apply generally if only we assume that Weber's law holds universally. This assumption would imply that all local relational time encodings will be necessarily 'scalar' and so will their convolution. The second comment is that early positions with regard to the importance of cognitive strategies for the processing of temporal information were usually based on the implicit assumption that, in coping with the temporal demands of the world around us, we mostly rely on general, domain-independent cognitive abilities. Gradually the insight has grown that this is an unrealistic presupposition. Temporal representations, it turns out, are highly specialized and related to behavioral modules that may have their origins deep in evolution (Barkow, Cosmides, & Tooby, 1992; Fodor, 1983). The role of domain-specific representations of time has been played down in past research. A much better analysis of specific behaviors is therefore indicated, in order to better understand their temporal structure. This means that we should be less concerned with events attached to a single time scale than with *ensembles* of (partially) ordered events that bring forth their own time encoding. This relativistic perspective has fundamental consequences for our understanding of the ways the organism deals with the dynamics of its environment, the topic to which I will now turn.

Dynamics

Time is the central concept of dynamics. The question to be answered is how dynamic relations as we perceive them happening in the world around us, are represented in the mind/brain. Do we, for instance, interpolate between discrete samples of information or do we carry differential or difference equations in our heads which we solve for specific instants? In short, what are the links between instantaneous states and their rates of change? (Rosen, 1985, p. 221).

According to Prigogine "everything is given in classical physics: change is nothing but a denial of becoming and *time is only a parameter, unaffected by the transformation that it describes*." (Prigogine, 1980, p. 215, emphasis added). But, as Prigogine argues, the classical view of dynamics is not the only possible one. There is a different approach, one in which time does not appear as a primitive term but as *derived*. In this case time is indeed defined in terms of the dynamic properties—place and momentum, say—of the system under consideration. As such time is expressed as an operator that allows the system's dynamic relations to hold homogeneously for the entire system. Thus, by expressing the relation between place, velocity, and time in terms of place and velocity as primitives, time appears as a derived concept, $t = s/v$. In other words, t is chosen such that the relation s/v holds homogeneously for the entire system. More generally, the time encoding is chosen such that some combination of system variables is minimized.[2] This may seem like a very complicated and tortuous path to arrive at something very trivial, but what it really amounts to is that for any orderly behaving (non-chaotic) system there is always a possibility to choose a time representation which minimizes the complexity of the system's dynamics with respect to some criterion such as motion, energy loss, memory load, or pattern complexity. In terms of everyday perception humans are capable to perceive natural rates of real-world events. Behaviors that differ too much from their prototypical values are recognized instantly as abnormal, say, as funny or threatening. Again, for many event-types we appear to have functional modules at our disposal, some acquired by evolution over the ages and some acquired in the course of our life. This may not only explain why we can perform some complex temporal tasks so well, but also why we find others so notoriously difficult.

In classical dynamics a system is conventionally represented by a trajectory in what is known as *phase space*. This is a diagram showing the system's evolution over time in terms of place (p) and momentum (q). The phase space representation does not contain time as an endogenous variable: if we wish to relate a trajectory to specific points in (absolute) time, we have to label the appropriate points on the trajectory.[3] The exogenous status of time in classical dynamics means that the age of a system is treated as independent of the state of the system. Adopting the approach outlined here means that aging, or 'becoming', is now an intrinsic property of a system. At the same time it is no longer possible to speak of *the* age of a system. Age emerges as a mixture of ages if considered at the microlevel, and this mixture determines the age of the ensemble at the macrolevel. This unorthodox approach "modifies our traditional view of time, which emerges now as a kind of average over 'individual times' of the ensemble" (Prigogine, 1980, p. 210). This introduces a wave-like representation and that is precisely also what (Dennett & Kinsbourne, 1992) seem to have had in mind when they proposed their 'Multiple Draft Model' of information processing.

The 'Multiple Draft Model'

Conventional wisdom has it that the encoding of perceived events proceeds in well-defined chunks and that each encoding is completed at a specific instant. Recently this was put in doubt by Dennett and Kinsbourne (1992; see also Dennett, 1992). This 'Cartesian model'—so called—derives from the assumptions of classical information processing theory according to which input information is processed in a succession of stages, the next stage waiting for a manageable chunk to be delivered (e.g., Sanders, 1983). This basic model imposes severe constraints on the flow of information which have been contradicted by the results of sophisticated reaction time experiments. An additional 'cascading" assumption, namely that successive stages may partly overlap and thus may receive inputs from the previous stage before that stage has completed its work, has been shown to relax some of the severest constraints of the basic stage model, but this assumption still appears to be insufficiently radical to account for some surprising empirical results discussed by Dennett and Kinsbourne.

One such result is the so-called color phi-phenomenon. If two identical lights at some angular distance away from each other flash in alternation, an observer will perceive this events as a single light staying on and moving to and fro between the positions of the individual lights. This has long been known as the phi-phenomenon. In its colored version, discovered by Kolers and von Grunau (1976), the two lights are presented in different colors, say red and blue. In this condition the observer will see the 'moving' light suddenly change color at a point halfway between the two positions. This result is puzzling since it seem to require that the observer be able to anticipate a future input (the color of the second light).

Color-phi and other paradoxical phenomena have motivated Dennett and Kinsbourne to abandon the 'Cartesian model' and to propose a radically different processing model, the so-called 'Multiple Draft Model', which assumes that information processing is essentially *distributed* in (neural) space and time. This assumption enabled them to account for perceptual phenomena in which there appears to be a conflict between the actual order of events as presented to the observer and their perceived order, as in the case of the color phi-phenomenon. The model assumes that elementary processing mechanisms each have there own timing distribution, but that these are not integrated into one single temporally definite stream of perceived events. There is only "a parallel stream of conflicting and continuously revised contents" and consequently "the temporal order of subjective events is a product of the brain's interpretational process, not a direct reflection of events making up those processes" (Dennett & Kinsbourne, 1992, p. 183).

The dynamics of the present

The psychological present is the focus of human experience. Phenomenologically it appears as a privileged, moving point in time, the *Now*. Physically there appears to be no basis for this *hic et nunc*: real world events may occur simultaneously at any point *tx* of a time scale, but this does not, by itself, create an experience of present. Apparently a privileged present requires a conscious observer capable of observing the co-temporality of these events within a single representational frame of reference. The psychological present, rather than being the durationless knife edge between past and future, also has a certain temporal width, variously estimated to lie in a range between, roughly one-tenth of a second and ten seconds. Within this *time window* events appear to occur and gradually to recede into the past (James, 1890/1950; Husserl, 1964).

The psychological present allows the organism to integrate the various elements of information processing into one coherent package of information, that is, a meaningful scene, event, frame, or idea. As such the mechanism leading to the awareness of a psychological present may be seen as a quantization, a *coagulation of reality*. Incoming information and outgoing information may be continuous and show all the characteristics of a 'multiple draft', but eventually there is, it seems, convergence towards a more or less stable, syntactically and semantically discrete internal representation. Memory storage and retrieval rely on such 'coagulated', that is, interpreted inputs and outputs: we remember semantically coherent constituents of a situation, an event, or a thought, never the second half of one thought together with the first part of the next. As the late Paul Fraisse once observed, we remember the tic-tac of the clock, never the tac-tic. Given the subtle syntactic and semantic processing that is going on all the time whilst a human being is interacting with his or her dynamic environment, it is likely that the psychological present is intrinsically related to this cognitive activity. In other words, the psychological present and any coagulation of events are dictated by the syntactic and semantic structure of the environment and the actions being performed, rather than by some fixed rate driving process or a traveling, but otherwise passive, window. Taking these structural aspects into account, a flexible and dynamic parsing model for the psychological present emerges.

The mechanism underlying the psychological present can be thought to operate as follows (e.g., Kunst, 1978; Jones, 1976; Michon, 1978). In order to cope with its environment in a coherent and efficient fashion, the observer will at some point in time be induced to pay attention to a stimulus event. At that point a fresh psychological present will begin to evolve as a result of an elementary, automatic cognitive activity known as *tuning*. Tuning is a continuous and automatic process of parsing and interpreting the world and anticipating what will happen next, on the basis of the incoming stimulus information and aided by the cognitive strategies and expectations of the person. If, and as long as, the anticipation is confirmed by further incoming information and by the results of the parsing process, the current present will remain intact, that is, it will become longer and longer. However, as soon as a mismatch between anticipation and reality occurs that cannot be revised by backtracking, the parsing process is interrupted (and the present terminated). Its contents up to that point, if meaningful, that is, if structurally and semantically ‘closed’ are then transferred to permanent memory. At the same time, a new start is made, repeating the process of initializing and (dis)confirming a prediction about the events as they are expected to unfold. This process is similar to the process of parsing linguistic inputs. There the flow of speech sounds is analysed ‘on line’ and then ‘packaged’ and stored as integral constituents. Listeners do not wait for a sentence to be completed before they start interpreting it; sometimes this will lead to problems, for instance in sentences such as *The boat sailed to Rotterdam / arrived at the dock*, where the second part of the sentence totally uproots the meaning of *sailed* as understood in the context of the first part of the sentence: suddenly we expect commas around the sub-clause *sailed to Rotterdam* (Michon, 1978).

The temporal parameters of this parsing process can be estimated from a variety of empirical data. Starting from the zero-point at which a present is beginning to evolve, the onset of the process may is initiated as early as 20-25 milliseconds after stimulus onset. At 250-300 milliseconds a present may be ‘aborted’ if no fitting parsing model is discerned. This will occur if the input information is essentially random or if lack of relevant knowledge, stress or other detracting factors prevent a subject from properly attending to the input. At the other end of the scale the length of a psychological present is constrained by the capacity of working memory: to retain information in working memory continuously for more than 20 or 30 seconds, it must be refreshed (rehearsed), which will interfere with the effort to sustain the ongoing process of parsing and interpreting. On average the length of the psychological present in everyday circumstances will be found to be of the order of 2-5 seconds. It is no accident that many naturally and culturally determined situations and events have an internal structure with components or constituents that fall within this 2-5 second range.

Dynamic time encodings

The variety of dynamic time encodings may be illustrated by the examples that follow. The first is the genetic theory of time proposed by J. T. Fraser, the second is the representation of discrete time. These two examples claim a certain universal generality that goes beyond a specific category of episodes or events. In the third place I will briefly outline a number of metaphorical time encodings that rely on the specific dynamics of the system to which they apply. Each of the latter encodings has been or is still playing a role in behavioral research and each has reached at least some level of formal representation. Together they are illustrative of the main thesis of the present article: for each the time encoding appears to be derived from, or at least supportive of the specific dynamic features of the event category to which it is applied.

According to J. T. Fraser, founder of the International Society for the Study of Time, “[t]ime had its genesis in the early universe, has been evolving, and remains developmentally open-ended. (…) A detailed inquiry reveals that the evolutionary character of time is already implicit in the ways time enters physical science in particular and natural science in general” (Fraser, 1982, p. 1). Fraser holds that there are five stable, hierarchically related ‘natural’ levels of temporality, each of which has emerged at a particular stage of development of the universe. Hierarchical means here that properties which emerged at a lower level remain ‘available’ at the next higher level.

(1) Atemporality. The first stage, atemporality, derives from the behavior of the elementary particles with zero rest mass, *viz.* photons. All photons move at the (constant) speed of light and consequently any ‘temporal’ relation other than simultaneity is meaningless.

(2) Prototemporality. The second stage, prototemporality, is represented by the elementary particles with non-zero rest mass, such as protons, electrons, etc. This is the realm of quantum mechanics and it defines a time encoding which orders events, if perhaps only locally or statistically.

(3) Eotemporality. The domain of aggregated matter, from molecule to milky way, determines the third stage. It is described by mechanics, classical as well as relativistic. Its proper time encoding is called eotemporality (after Eos, the Olympian goddess of dawn). Eotemporality is the linear time of mechanical clocks.

(4) Biotemporality. At the fourth level the ‘natural’ time encoding is biotemporality. It defines a ‘physiological present’ which serves to establish the interfacing, or tuning, between processes inside the organism (or system) and events in the environment. Biotemporality is irreversible because evolution and development cannot be undone.

(5) Nootemporality. Finally the domain of (human) knowledge determines nootemporality in which events have a definitive position on an individual time scale, a personal history which defines a conscious present, a privileged now, but also “beginnings and endings”.

If we accept, with Fraser, that these five representations of time constitute a coherent hierarchy, we must be able to specify a theoretical framework that will be strong enough to formally support this rather gigantic cosmological structure. Fortunately such a framework appears to exist. A formal structure that is consistent with the properties of Fraser’s five levels of temporality is linear measurement theory (Michon, 1985b, 1989). Since each level of temporality must possess at least one time encoding, a hierarchical dependency should exist between these encodings. In linear measurement theory quantitative scales are the actual representations of these relations (Narens, 1981) and it is possible to associate a distinct scale type with each level of temporality. Interestingly enough the formal operations and properties which are naturally applied to each of Fraser's temporalities coincide with the operations and scales derived from the theory of measurement. The required scales include the familiar nominal, ordinal, interval, ratio and absolute scales known from psychophysics. In addition Narens has shown that precisely this set of scales constitutes a canonical, hierarchically related set. Fraser's levels of temporality appear therefore to represent the temporal interpretation of this well-established set of canonical scale types. The nominal scale corresponds with atemporality and the ordinal scale with prototemporality. The interval scale corresponds with eotemporality, allowing metric but reversible relations of distance and duration. The ratio scale accommodates the characteristics of biotemporality, *direction* in particular. Finally the absolute scale corresponds with nootemporality, each event having its own, unique, place defined on the time scale of personal history.

DISCRETE TIME

A conceptually important time encoding is that by which discrete-time systems are described. Examples of such systems are board games like chess or Go, and computer programs. Compared with continuous-time mechanical systems, the behavior of discrete-time systems is essentially different. The first can follow only one trajectory in phase space (unless they are of the chaotic, bifurcating, variety). For discrete time systems, on the other hand, a transition from one state to the next may be one of a set of alternatives. The rules (transitional probabilities, production rules, rules of inference) will constrain which states may be reached from a given state. Thus, each legitimate trace constitutes a game, or a proof. In such systems the rank order of states (and the associated moves or steps) constitute a time encoding which defines a set of successive instants. The time thus defined is discrete, irreversible. It is also *rate-independent*, meaning that from the record of a game of chess or a mathematical proof one cannot infer how much time it takes to reach the next state. Psychologically speaking this model of time plays a very important role, not only in games and the various forms of problem solving and proving things we normally engage in, but also because of the way we encode and store incoming information. The dynamics of the present, which I described earlier as a process of coagulating the flow of events into semantically meaningful and therefore memorizable 'chunks', relies on it: in the parsing process explicit temporal references are eliminated, and the parsed events appear to be manipulated mentally in a sequential, but not in a temporal way. Temporal relations of a stored episode can often be reconstructed, but only by 'reliving' the episode, not in the 'simulated time' of our memories. This perspective has, thus far, not been worked out properly, but some hints in this direction were introduced some time ago by Anderson (1983), when he distinguished temporal strings as a special type of information that humans may process, in addition to spatio-visual and propositional information. Anderson emphasized that temporal strings carry ordinal but not interval information; he also referred to a number of characteristic features of speech and language understanding that suggests a considerable loss of precise temporal information. Finally, the relatively poor performance of humans when estimating time periods would, in his opinion also support the idea that temporal encoding eliminates a good deal of the temporal information from the original events, partly by failing to encode it at all, but partly also by simplifying the temporal relations between events in the course of the parsing process. Reconstruction is possible later, although it requires a context in which the precise temporal relations do have substantive importance.

If temporal information is indeed encoded in terms of ordered strings, with other temporal attributes such as duration or temporal locus (date) added-on if required, the question becomes how order is encoded in the subject's mind. There is indeed a 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 adequately represented as a stored *versus* actual relation (Michon & Jackson, 1984). Even if order would turn out to be a necessary temporal stimulus, it cannot be the only relevant one. In the first place there is no valid reason to assume that the order of impressions will determine the impression of order. On the contrary, as we saw earlier, Dennett and Kinsbourne (1992) have argued forcefully that the temporal locus of an event is determined not on the basis of a single perceptual act, but on some averaging of a parallel stream of conflicting and continuously revised contents. At best these would provide partially ordered strings that would then have to be averaged and mapped into a single time line or a consistent narrative.

QUANTIFIED METAPHORS

Basic metaphors are like naive system theories, that is, they are dynamic conceptual structures or schemata that are "general enough to be of use in representing information from distinctly different events that are similar to the extent that they share elements of the same structure" (Schank, 1982, p. 222). Such metaphors permit us to encode and comprehend objects and events in terms of a coherent and reasonably consistent world view. In this sense also, "the use of metaphor is one of many devices available to the scientific community to accomplish the task of accommodation of language to the causal structure of the world" (Boyd, 1979, p. 358). I wish to add, in line with what was said thus far, that such metaphors are not arbitrary. Metaphors cannot take just any conceivable form, but, instead, display considerable morphological stability. The following examples may illustrate the variety of temporal analogies adopted. They do not exhaust the range of possibilities by any means, but each is based on a substantial body of theoretical and empirical evidence.

(1) Temporal perspective. The encoding analogy for the temporal perspective is that of viewing a landscape. Here we find studies to determine how people plan their future; which roads they plan to travel towards their future; how near are next (or last) week, month, or year; and where their temporal horizon prevents them from looking farther ahead.

(2) Critical path analysis. PERT, STRIPS, and other planning procedures take actions-to-perform, their sequential dependencies and time constraints to produce a schedule for performing those actions and to describe which trajectories to travel and at what speed.

(3) Space-time geography. Geographers have studied the space-time coordinates of activities. Activity patterns can be represented as a trajectory in space-time and the formal properties of these trajectories analysed (see e.g., Carlstein, Parkes & Thrift, 1978).

(4) Time management. There is a host of highly popular ideas on how to remain in charge of one's time. They all propose the management of one's personal life in a very strict, algorithmic way. The algorithms involved have been ritualized and lie at the root of the very profitable business of time management agenda's and trainings.

(5) Temporal span of control. The initial empirical study of what is known as the temporal span of control was carried out by (Jaques, 1982). In his hands it evolved, among other things, into a strategy for paying workers in industry. The longer the time span of control required for adequate task performance or supervision, the higher income should be.

(6) Dynamic programming. Dynamic programming seeks to optimize decision making if the problem is stated recursively in terms of a difference equation. There have been some attempts at using dynamic programming as a model of repetitive decision making in humans.

(7) Time preferences. As part of performing one's daily pattern of activities one must know when a specific action should be performed (or not). People may specify their preferences which can then be used, for instance, to determine a set of optimal departure times of a transit bus service.

(8) Temporal duel. The temporal duel (Kahan & Rapoport, 1974, 1975) is inspired on the classic Western film *High Noon.* Two duelists approach each other at a uniform rate; each has a revolver with n bullets which he (or she) may fire, one at a time at $t > t_0$. Their problem is how many bullets to shoot and when, if the probability of hitting the opponent is varied.

(9) Temporal logic. Over the last 30 years modal logic, and more specifically the logic of time, has made tremendous progress. The most fertile idea in this area has been not to take instants as the point of departure but intervals. Relations between intervals provide a much richer domain of discourse than relations between instantaneous points in time. Formalization in this field make it possible to equip robots and decision support systems with a sense of time (Jackson, Akyürek & Michon, 1993).

(10) Temporal grids or grains. In several fields—notably in music psychology (Jones, 1990) but also in structural information theory of perception (Leeuwenberg & Buffart, 1979; Van der Helm, 1988)—authors have come up with the idea that our perspective on the temporal scale changes its grain or resolution as a function of the level of attention for detail we need to perform a certain task.

Temporal narrativity: good stories tell themselves

The relational approach to the temporal structure of cognition and behavior extends far beyond the domain of individual behavior that we have considered thus far. Our conclusion that the stored representations of separate episodes and events carry their own time encodings because we seem to remember 'worlds'—as understood by Goodman (1984)—rather than chains of calendar events. This emphasis on the generative quality of experience as opposed to the conventional instrumental (associationist) accounts finds its expression in the context of narrative theory. In the words of Ricoeur (1984), "time becomes human to the extent that it is articulated through a narrative mode, and narrative attains its full meaning when it becomes a condition of temporal existence."

A number of important novelists have exploited the temporal structure of the 'worlds' they envisioned, among them Marcel Proust, Thomas Mann, John Fowles, and more recently the Danish novelist Peter Høeg.[4] The worlds they create give rise to a temporal framework that is consistently convincing to the reader as well as to the characters in the novel itself. There are numerous detailed studies of the required characteristics that make the temporal structure of a narrative convincing and they all reach the conclusion that *good novels write themselves*. The temporal grammars inherent in such novels impose just the right kind of constraint on the behavior of the protagonists, leaving them their 'freedom' to act within these constraints. This is achieved by a plethora of 'temporal strategies' some of which seem to have their counterparts in the encoding of events in the individual's private life, whereas others are rather more 'tricks' to induce a specific temporal attitude in the reader. Analysis (e.g., Fawkner, 1984) reveals the full potential of various schemes that include, among many others, interlocking but partially ordered fragments, forking, and incompatible perspectives. A powerful example is the ordeal of the protagonist in John Fowles' *The Magus* (Fowles, 1977):

Nicholas Urfe (note the resemblance of this name with Orpheus) is a young teacher of English who accepts his first job in a boarding school on Phraxos, a small Greek island not far from Athens. There he gets involved with a Mr. Conchis, the wealthy and erudite, if mysterious owner of a large estate on the island. In time Nicholas is drawn into an intricate web of play and trickery. (Readers will recognize these as rites of passage and sooner or later appreciate their Orphic character.) One of the 'plays' in which Nicholas is made to participate re-enacts an episode form the German occupation of Phraxos during the Second World War. As part of a reprisal the Germans wind up a group of villagers and take them to a place where they are locked in to be executed the next morning. Nicholas happens to be among them. This re-enactment is staged so realistically that when at last he comes to himself in his prison he seemingly has lost all sense of time and is ready to accept as real what is happening to him then and there. We could well say that this episode generates its own space and its own time: *good stories tell themselves.* At that point, however, one of the more 'humane' German guards—an authentic German, authentic as all actors in Conchis' plays are—offers Nicholas a cigarette. Not surprisingly the cigarette is authentic too. It bears an inscription on the side: between two little swastika's one reads "*1943 - Leipzig dankt euch."* But, when Nicholas lights the cigarette it tastes distinctly stale. For Nicholas this suddenly destroys the magic reality of the episode: in 1943 the cigarette would have tasted fresh!

In the performing arts this power of intrinsic temporality of events and episodes is common too, especially in dance and in some forms of theater. The classical European theatrical tradition was fairly impoverished in this respect. It demanded a unity of place, time and action, which only disappeared in the course of the 20th century, largely under the influence of the cinema. In the Japanese Noh theater a completely different time structure prevails. Noh is difficult to characterize, being perhaps more dance than play. Its narrative structure may, on the surface, seem extremely simple. Take as an example a play named *Yoroboshi.*

Yoroboshi is a blind youth begging on the steps of Shitennoji Temple. He holds up the hem of his kimono to receive alms, but catches falling plum blossoms instead. Though he cannot see, he can smell their beauty. He realizes that if the eyes of the soul are open, one can live in spiritual happiness and he dances for joy at his newly found insight. His father who had disowned him sees this and moved by the boy's faith leads him back home.[5]

Underneath this simple surface, however, one may find many levels of additional, deeper meaning. The 'greater' the play, the more knowledge and understanding is required for full appreciation. Progressive understanding may eventually reveal perhaps as much as three or four levels of meaning. Combined with the extremely slow and restrained movements of the actors, a time structure will emerge that easily induces a total loss of external temporal reference.[6]

Similarly the narrative structure of history may evoke special and highly non-linear time encodings. The nature and extent of historical narrative have been analysed beautifully by Wilcox (1987). The author compares the intrinsic time structure of the work of such classical historians as Herodotus and Thucydides. Characteristic for their work is the tight narrative character, which may lead to either of two typical relational temporal models. In the first, which we may call *episodic time*, temporal structure derives entirely from narrative requirements relating to the point the author wishes to make about a particular person (king, sage) or event (battle, famine). The second model, *concurrent time*, traces independent narrative lines that may occasionally merge and then drift apart again in an attempt to show the interrelations between several events. The latter model differs from the first in that it allows reference to a general calendar. Whereas no historical order can be determined from episodes under the first model, the second model provides at least a partial ordering that may or may not be sufficient for constructing a correct linear representation of the relevant events. These and numerous other relational models—proposed, among others, by Bishop Ussher who placed the moment of Creation in the year 4004 B.C.—have all but disappeared from the canon of modern history since absolute Newtonian time took hold of Western science and humanities. Only towards the end of the 20th century the relational perspective returns, this time under the disguise of post-modernism, a trend Wilcox carefully traces in his monograph.

Conclusion

In this article I have argued for a relational approach to time. Rather than referring to time as an external chronometric reference, this approach honors the concept of multiple time encodings: times—plural—are seen as the intrinsic products of a variety of dynamic representations. What these time encodings have in common is that they provide a conceptual (computational, cognitive) anchor for the way we perceive or represent the system from which they derive. For most systems a time encoding can be derived that will minimize the complexity of describing the dynamics involved. The exquisite human capability of coping with change relies on evolved and acquired mechanisms and strategies that can detect such 'minimal' system representations. The examples discussed in the text were taken from a wide range of disciplines. This suggests that the concept of local, relativistic representations of time plays a distinct role in scientific explanation, a role, in fact, that seems to have been gaining importance in recent years.

Notes

[1] Earlier versions of this chapter were presented at the Conference on Time and Mind in Regensburg, Germany, 6-8 November 1994, the Symposium on Time and the Dynamics of Behaviour, Liège, Belgium, 2-3 December 1994, and the International Symposium 'La psychologia del tempo', San Marino, Italy, 5-6 May 1996.

[2] A spatial analogy is the Copernican representation of the solar system, which substantially reduced the complexity of representing planetary motion by means of epicycles.

[3] There is a similarity with topographical maps of mountainous areas on which the (horizontal) distance between two locations does not tell very much about the time it takes to travel from one to the other.

[4] The latter has received international recognition as a time novelist through two of his works: *Borderliners* (1993, Eng. transl. 1994) and *The history of Danish dreams* (1988, Eng. transl. 1995). The English translations were published by Harvill Press, London.

[5] From an anonymous and undated program booklet.

[6] Despite a considerable experience in the domain of subjective time estimates I have found, to my genuine surprise, that an hour's performance can be over in what 'feels' like five or ten minutes.

References

Anderson, J. R. (1983). *The architecture of cognition.* Cambridge, Massachusetts: Harvard University Press.

Barkow, J. H., Cosmides, L., & Tooby, J. (1992). *The adapted mind: Evolutionary psychology and the generation of culture.* New York: Oxford University Press.

Boltz, M. G. (1993). Time estimation and expectancies. *Memory and Cognition, 21*, 853-863.

Boyd, R. (1979). Metaphor and theory change: What is "metaphor"? In A. Ortony (Ed.), *Metaphor and thought* (pp. 356-408). Cambridge: Cambridge University Press.

Carbonell, J. G. (1982). Metaphor: An inescapable phenomenon in natural language compre-hension. In W. G. Lehnert & M. U. Ringle (Eds.), *Strategies for natural language processing* (pp. 415-434). Hillsdale, NJ: Erlbaum.

Carlstein, T., Parkes, D., & Thrift, N. (1978). *Human activity and time geography.* (Vol. 2). London: Edward Arnold.

Dennett, D. C. (1992). *Consciousness explained.* Harmondsworth, UK: Allen Lane/ Penguin.

Dennett, D. C., & Kinsbourne, M. (1992). Time and the observer: The where and when of consciousness in the brain. *Behavioral and Brain Sciences, 15*, 183-247.

Fawkner, H. W. (1984). *The timescapes of John Fowles*. London: Associated University Press.

Fodor, J. A. (1983). *The modularity of mind: An essay on faculty psychology*. Cambridge, MA: MIT Press.

Fowles, J. (1977). *The Magus: A revised version*. London: Cape.

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.

Freyd, J. J. (1992). Dynamic representations guiding adaptive behavior. In F. Macar, V. Pouthas, & W. J. Friedman (Eds.), *Time, action and cognition* (pp. 309-323). Dordrecht, The Netherlands: Kluwer.

Gibbon, J. (1991). Origins of scalar timing. Special Issue: Animal timing. *Learning and Motivation, 22*, 3-38.

Gibbon, J. (1992). Ubiquity of scalar timing with a Poisson clock. *Journal of Mathematical Psychology, 36*, 283-293.

Goodman, N. (1984). *Of mind and other matters*. Cambridge, MA: Harvard University Press.

Hayes, P. (1978). The naive physics manifesto. In D. Michie (Ed.), *Expert systems in the micro-electronic age* . Edinburgh: Edinburgh University Press.

Hayes, P. (1985). The second naive physics manifesto. In J. R. Hobbs & R. C. Moore (Eds.), *Formal theories of the commonsense world* (pp. 1-36). Norwood, NJ: Ablex.

Helm, B. P. (1985). *Time and reality in American philosophy*. Amherst, MA: University of Massachusetts Press.

Hobbs, J. R., & Moore, R. C. (1985). *Formal theories of the common sense world*. Norwood, NJ: Ablex.

Husserl, E. (1964). *The phenomenology of internal time-consciousness* (J. S. Churchill, Trans.). Bloomington: Indiana University Press.

Jackson, J. L., Akyürek, A., & Michon, J. A. (1993). Symbolic and other cognitive models of temporal reality. *Time and Society, 2*, 241-256.

James, W. (1890). *The principles of psychology*. (authorized edition 1950, Vol. 1). New York: Dover.

Jaques, E. (1982). *The form of time*. New York/London: Crane Russak/Heinemann.

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. (1990). Musical events and models of musical time. In R. A. Block (Ed.), *Cognitive models of psychological time* (pp. 207-240). Hillsdale, NJ: Erlbaum.

Jones, M. R., & Boltz, M. (1989). Dynamic attending and responses to time. *Psychological Review, 96*, 459-491.

Kahan, J. P., & Rapoport, A. (1974). Decision of timing in bipolarized conflict situations with complex information. *Acta Psychologica, 38,* 183-203.

Kahan, J. P., & Rapoport, A. (1975). Decision of timing in conflict situations of unequal power between opponents. *Journal of Conflict Resolution, 19*, 250-270.

Killeen, P. R., & Weiss, N. A. (1987). Optimal timing and the Weber function. *Psychological Review, 94*, 455-468.

Kolers, P. A., & von Grunau, M. (1976). Shape and color in apparent motion. *Vision Research, 16*, 329-335.

Kung, T. J., & Richards, W. A. (1988). Inferring "water" from images. In W. A. Richards (Ed.), *Natural computation* (pp. 224-233). Cambridge, MA: MIT Press/ Bradford.

Kunst, J. (1978). *Making sense in music: An enquiry into the formal pragmatics of art.* Ghent, Belgium: Communication and Cognition.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago, IL: University of Chicago Press.

Leeuwenberg, E. L. L., & Buffart, H. F. J. M. (1979). *Formal theories of visual perception.* New York: Wiley.

Leyton, M. (1992). *Symmetry, causality, mind.* Cambridge, MA: MIT Press.

Marr, D. (1982). *Vision.* Cambridge, MA: MIT Press.

Michon, J. A. (1972). Processing of temporal information and the cognitive theory of time experience. In J. T. Fraser, F. C. Haber, & G. H. Mueller (Eds.), *The study of time* (Vol. 1, pp. 242-258). Berlin: Springer-Verlag.

Michon, J. A. (1978). The making of the present: A tutorial review. In J. Requin (Ed.), *Attention and performance* (Vol. 7, pp. 89-111). Hillsdale, NJ: Erlbaum.

Michon, J. A. (1985a). The compleat time experiencer. In J. A. Michon & J. L. Jackson (Eds.), *Time, mind, and behavior* (pp. 20-52). Berlin: Springer-Verlag.

Michon, J. A. (1985b). Temporality and metaphor. In J. A. Michon & J. L. Jackson (Eds.), *Time, mind, and behavior* (pp. 288-296). Berlin: Springer-Verlag.

Michon, J. A. (1989). Timing your mind and minding your time In J. T. Fraser (Ed.), *Time and mind: Interdisciplinary issues.* (Vol. 6, pp. 17-39). Madison, CT: International Universities Press.

Michon, J. A. (1990). Implicit and explicit representations of time. In R. A. Block (Ed.), *Cognitive models of psychological time* (pp. 37-58). Hillsdale, NJ: Erlbaum.

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* (Vol. 423, pp. 298-321). New York: New York Academy of Sciences.

Miller, G. A., & Johnson-Laird, P. N. (1976). *Language and perception.* Cambridge: Cambridge University Press.

Narens, L. (1981). On the scales of measurement. *Journal of Mathematical Psychology, 24*, 249-275.

Pinker, S. (1994). *The language instinct: The new science of language and mind.* London: Penguin/Allen Lane.

Prigogine, I. (1980). *From being to becoming: Time and complexity in the physical sciences*. San Francisco: Freeman.

Richards, W. (Ed.). (1988). *Natural computation*. Cambridge, MA: MIT Press/Bradford.

Ricoeur, P. (1984). *Time and narrative* (D. Pellauer, Trans.). (Vol. 1). Chicago: University of Chicago Press.

Rosen, R. (1985). *Anticipatory systems: Philosophical, mathematical and methodological foundations*. Oxford: Pergamon Press.

Sanders, A. F. (1983). Towards a model of stress and human performance, *Acta Psychologica, 53,* 61-97.

Schacter, D. L. (1996). *Searching for memory*. New York: Basic Books.

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: Erlbaum.

Schank, R. C., & Abelson, R. P. (1977). *Scripts, plans, goals, and understanding: An inquiry into human knowledge structures*. Hillsdale, NJ: Erlbaum.

Sklar, L. (1974). *Space, time, and spacetime*. Berkeley, CA: University of California Press.

Tulving, E. (1983). *Elements of episodic memory*. (Vol. 2). Oxford: Clarendon Press.

Van der Helm, P. A. (1988). *Accessibility and simplicity of visual structures.* Ph.D. dissertation, Catholic University of Nijmegen. Nijmegen, The Netherlands.

Wearden, J. H. (1991). Do humans possess an internal clock with scalar timing properties? Special Issue: Animal timing. *Learning and Motivation, 22*, 59-83.

Wearden, J. H. (1992). Temporal generalization in humans. *Journal of Experimental Psychology: Animal Behavior Processes, 18,* 134-144.

Wilcox, D. (1987). *The measure of times past.* Chicago, IL: Chicago University Press.