

An Attentional-Gate Model of Prospective Time Estimation¹

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1. INTRODUCTION

Time estimation is a cognitive process contingent upon contextual factors. Block (1989, p.334) argued that "a complete understanding of any kind of temporal experience is possible only if we consider complex interactions among all of these factors". Some of the factors which contribute substantially to the understanding of time estimation processes are the estimation paradigm, the estimation method and stimulus information processing load during the estimated interval (Block, 1989; Hicks, Miller, & Kinsbourne, 1976; Zakay, 1990). Jones and Boltz (1989) showed that the structure of events comprising the to be estimated interval affect time estimation processes as well.

The need to rely on complex interactions among contextual factors for explaining time estimation processes emerges as a result of a puzzling picture of contradicting empirical findings reported in the literature. In some studies (e.g., Boltz, 1991; Ornstein, 1969; Thomas & Brown, 1974), estimated durations of intervals filled with some task demanding

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information processing were reported to be longer as compared with empty intervals during which subjects were not required to perform any task. In contrast to the above, the opposite finding has been reported in other studies (e.g., Zakay, Nitzan, & Glicksohn, 1983). A positive monotone relationship between estimated duration's magnitude and stimulus information processing load during an estimated interval has been reported in some studies (e.g., Ornstein, 1969; Vroon, 1970; Zakay, & Fallach, 1984), while the opposite finding of a negative monotone relationship has been found by others (e.g., Curton & Lordahl, 1974; Fortin & Rousseau, 1987; Grondin & Macar, 1992; McClain, 1983; Zakay, 1989).

Current models of time estimation can only account for one aspect of this complex pattern of results. The positive relationship between magnitude of estimated durations and stimulus information processing load during target intervals as well as the "filled time" illusion can be accounted for by models which view time estimation as a function of the amount of relevant information stored in memory. The negative relationship as well as findings showing estimated durations of empty time to be longer than estimations of corresponding filled intervals can be explained by attentional models.

The contextual change model (Block, 1978, 1989, 1990; Block & Reed, 1978) contends that estimated duration is a positive monotone function of the number of contextual changes which are coded in memory during a to-be-estimated interval. These changes reflect both contextual changes taking place in the external environment as well as internal events such as changes in meaning, cognitive strategies or states of mood. Poynter (1983, 1989; Poynter & Homa, 1983) argued that meaningful contextual changes divide a given time period into meaningful segments and consequently, estimated durations are a function of the degree to which an interval is segmented. It is clear, then, that the more complex the processing during a given period, the more are the expected cognitive changes in meanings and strategies and thus the greater the level of segmentation. The above arguments suggest a positive monotone relationship between estimated duration and non-temporal information processing load during a target interval. The same argument holds for filled versus empty intervals, with less changes occurring during empty interval than during an interval filled with a task demanding information processing.

Attentional models (e.g., Hicks, Miller, Gaes, & Bierman, 1977; Thomas & Weaver, 1975; Zakay, 1989) sometimes assume the existence of a cognitive counter whose operation requires mental resources. The operation of this counter reflects the level of temporal information processing during a given interval. Temporal information processing, whatever its nature, is not carried out automatically (Michon & Jackson, 1984) but requires attentional resources. It is plausible that temporal information processing is directed by the structure of events filling a time interval and can take various forms like grouping or counting some

repetitious element, etc. (Jones & Boltz, 1989). Time estimation is associated with the value of the output of the cognitive counter at the estimation moment. Because of capacity limitation (Kahneman, 1973), as non-temporal information processing load is reduced, more attentional resources are freed for the processing of temporal information, thus producing a negative monotone relationship between magnitude of estimated durations and non-temporal information processing load. According to the attentional model, "empty" time should produce higher duration estimates than filled intervals since during "empty" time non-temporal information processing load is assumed to be low.

In attempting to provide a unified explanation for these seemingly contradictory findings, Zakay (1989) adopted the contextualistic view (Block, 1985, 1989) and proposed that the processes mediating time estimation of short intervals (in the range of seconds and minutes) are governed by the time estimation paradigm, the time estimation measurement method and the temporal structure of events filling an estimated interval.

Zakay (1993) proposed a contingency model which is an elaboration of Thomas and Weaver's (1975) model. It postulated that each stimulus is analyzed by two processors, a time processor, P(T), and a non-temporal information processor, P(I). Estimated duration is a weighted function of both P(T) and P(I) where each processor's contribution to the overall estimation is proportional to the amount of attention allocated to it. Thomas and Weaver's model, however, lacks an explicit specification of the conditions governing the allocation of resources to each processor. This shortcoming prevents the derivation of specific predictions from the model. The contingency model attempts to overcome this specific problem. It is assumed that P(T) reflects the product of temporal information processing. P(I), however, is replaced here by a counter P(C), which reflects the amount of contextual changes which were perceived and coded during a target interval. Thus, P(C) reflects the number of meaningful segments which were perceived. The reason for replacing P(I) by P(C) is that P(I) represents a broad category of information processing while P(C) reflects a specific aspect of it, which was found empirically to be related to time estimation. When a subject is given prospective instructions telling him/her in advance that time estimation is required, high internal priority is assigned to the time estimation task (Zakay, 1992). As a result, the weight of P(T)'s contribution to the overall time estimate is increased respectively. In a retrospective time estimation, on the other hand, when subjects are required to provide estimates only at the completion of a target interval, priority, during the to-be-estimated interval is given to non-temporal information processing, including the processing of contextual changes. When a retrospective time estimate is requested, memory is searched and the number of contextual changes or of meaningful segments that are retrieved from memory is coded in P(C). Either P(T) or P(C) or both, can be selected as

sources of information upon which time estimation is based. This selection is governed by the reliability and availability of information stored in each processor.

The contingency model provides an explanation for the differences between prospective and retrospective time estimation and was supported empirically (Zakay 1993). A prediction stemming from the contingency model is that increasing the amount of segmentation of an estimated interval should increase its retrospective estimate but should not influence its prospective estimate. This prediction was indeed supported empirically (Zakay, Tsai, Moses, & Shahar, 1994).

Although the contingency model gained empirical support, some of the constructs which are used in it are quite ambiguous and do not have a clear cognitive definition. The most problematic constructs are those related to the prospective process. It is not clear what is the meaning of temporal information processing and what is the nature of $P(T)$. It is also not clear what is the meaning of focusing attention on time.

In order to solve these problems, it seems that some timing mechanism should be added to that part of the contingency model which deals with prospective time estimation. In other words, the contingency model which represents a family of timing-without a timer models should be turned to become a timing-with a timer model (Block & Zakay, 1995). In order to explore this possibility, internal-clocks models should be reviewed.

2. SCALAR-TIMING MODEL

The scalar-timing model (e.g. Church, 1984; Gibbon, 1991) accounts for duration discrimination and perception by proposing an internal clock, memory stores and a decision mechanism. The internal-clock consists of a pacemaker, a switch and an accumulator. The pacemaker generates more or less regularly spaced pulses at a fixed rate per second. When the organism perceives an external timing signal, signaling the beginning of a time period, the switch opens and the accumulator integrates and holds the total pulse count during the time period. The perceived duration is a monotone function of the total number of pulses transferred into a working memory store for comparison with the contents of the reference memory store. The reference memory store contains a long-term memory representation of the approximate number of pulses that were accumulated on past occasions. On each past trial, the total number of pulses is transferred from the accumulator to the reference memory store. This transfer occurs following a multiplicative transformation, with some bias K^* , the "memory constant" (see Church, 1984).

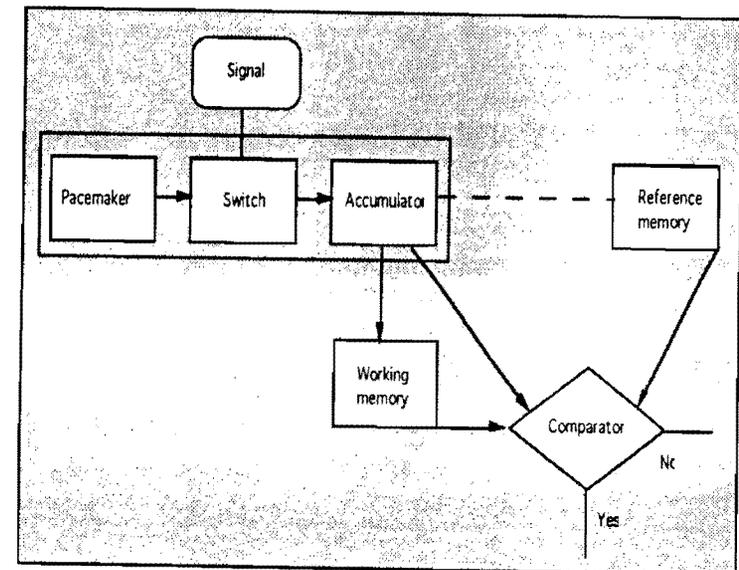


Figure 1

A model of scalar-timing model in animals (Church, 1984).

Scalar timing theory has enjoyed considerable success as a quantitative theoretical account of animal performance in a wide variety of time-related behavior during relatively short time periods of seconds or minutes.

3. SCALAR-TIMING MODEL AND HUMAN TIMING BEHAVIOR

Some recent research comparing human and animal timing behavior provided evidence for scalar timing in humans. Wearden (1991) conducted two experiments with normal adult human subjects in an analog of a time interval bisection task, frequently used with animals. Temporal bisection is a discrimination task in which subjects first experience two samples, one of them (S) lasting less than the other (L). Having experienced these samples, the subject is presented with probe stimuli of variable duration, t . The task is to judge whether

the duration of t is closer to S or to L (Rodriguez-Girones & Kacelnik, 1994). A bisection point, defined as the duration, classified as "long" on 50% of the trials, can be calculated.

Wearden (1991) found that the bisection point in humans was located at a duration just lower than the arithmetic mean of the standard "S" and "L" durations, whereas in animals' experiments the bisection point is usually located at the geometric mean. Allan and Gibbon (1991), however, reported two experiments in which normal adults, like animals, bisected at the geometric mean. To make the picture even more complicated, Rodriguez-Girones and Kacelnik (1994) found that the bisection point in humans lies somewhere between the arithmetic and the geometric mean.

There are two possible explanations for these seemingly contradictory findings. One explanation is that the exponent of the power function of time is higher in humans as compared with animals. Another possible explanation lies in the different nature of the time intervals which subjects experienced in the various studies. Allan and Gibbon (1991), for instance, used filled intervals, whereas Wearden (1991) used empty ones which were also shorter than those used by Allan and Gibbon. If this is the case, then, unlike animals, humans' timing behavior is influenced by the nature of an interval. In the same line of thought, Rodriguez-Girones and Kacelnik (1991, p.10) claim that in animal timing, the location of the bisection point seems deeply rooted at the geometric mean, but human subjects "insist in asserting their freedom of choice by having a somewhat nomadic bisection point".

Thus, it seems that human timing behavior does exhibit appropriate scalar properties, as was indicated in interval production based on chronometric counting (Wearden, 1993; Wearden & MacShane, 1988). However, it is also clear that human performance differs from that found in animals. Human timing behavior is more complex than animals' timing behavior. Scalar timing theory may still not be sufficiently elaborated to encompass the range of phenomena found even in restricted domains of time behavior in humans (Wearden 1993).

4. TREISMAN'S MODEL

Treisman (1963) proposed an internal clock model aimed at explaining human timing behavior. The model consists of a pacemaker, a counter, and a comparative mechanism (see Figure 2).

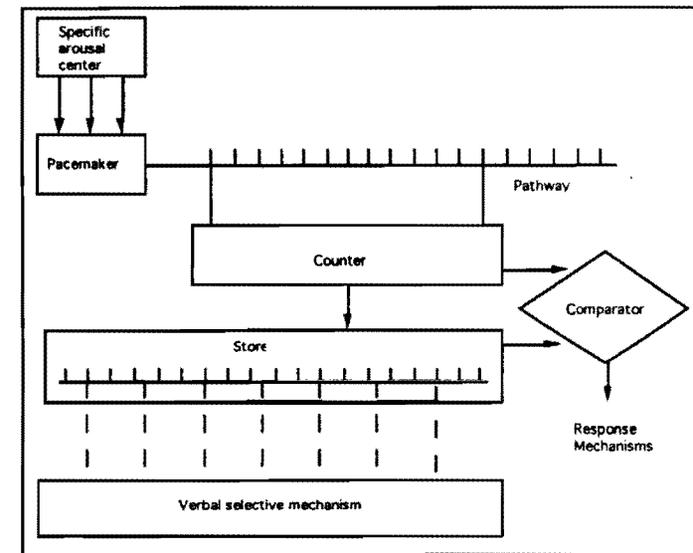


Figure 2
A model of a hypothetical internal clock (Treisman, 1963).

The pacemaker produces a regular series of pulses. In the first version of the model it was assumed that the rate of the pacemaker varies as a function of an organism's specific arousal state which is influenced by external events. In a later version of the model Treisman (1990, 1993) added a calibration unit which can modulate the constant rate of pulses emitted by the pacemaker as a function of variation in arousal level.

The counter records the number of pulses entering it from the calibrator. This count is transferred into a store and into a comparator mechanism. A verbal selective mechanism assists in retrieving useful information from the store. This is presumably a long-term memory store containing knowledge of correspondences between specific counts of pulses and verbal labels.

Although Treisman (1984, 1993) reports some evidence supporting his model, the model in its present format cannot handle complex human timing behavior as it cannot provide explanations for the influences of information-processing load and attention allocation on time estimation.

4. THE ATTENTIONAL-GATE MODEL

Internal-clock models which are successful in predicting animal timing behavior, seem limited as an explanation of human timing behavior (Block, 1990). What is needed, then, is a model which has scalar-timing properties and also considers the role of cognitive factors, such as attentional allocation.

We propose such a model which is based on the scalar-timing model and on Treisman's model, but we add to it a cognitive module in the form of an attentional gate (see Figure 3).

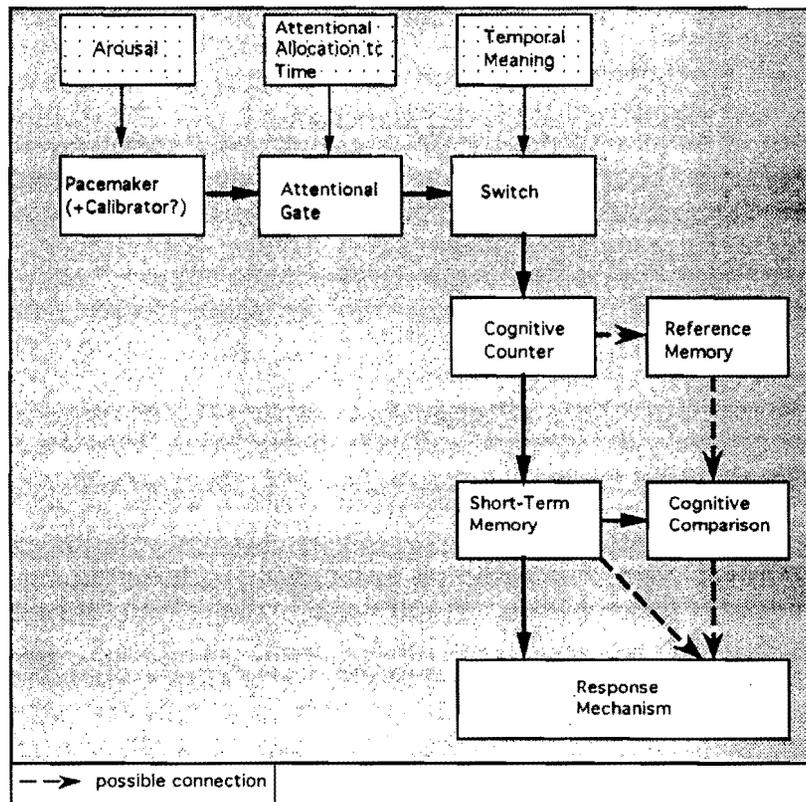


Figure 3
The attentional-gate model.

This gate is a cognitive mechanism controlled by the allocation of attention to time. If more attention is allocated, the gate opens wider or more fully, and more pulses emitted by the pacemaker can pass through and be transferred to the counter. Thus, when time is important and relevant (Zakay, 1992), the gate allows for more pulses to pass through. This is the case when prospective conditions prevail, but when time is not relevant like under retrospective conditions, or when most of the attentional resources are allocated for dealing with an important non-temporal task, the gate is closed and no pulses can pass through. Thus, attending to time is simply increasing the level of activity of the gate. Accordingly, P(T) consists of a pacemaker producing pulses at a constant rate (whether or not a calibration unit is required remains an open question), and a counter in which the pulses coming out of the gate are counted. There is still a need for a switch which opens or closes the counter. The switch operates in an "all-or-none" fashion and is governed by the temporal meaning assigned to stimuli. When a stimulus signaling the beginning of a relevant interval is perceived, the switch is opened, the counter is set at zero, and the flow of signals can be counted. When a stimulus signaling the termination of a relevant interval is perceived, the switch is closed, preventing more pulses from entering the counter and at the same time the count is transferred to short-term memory. The exact location of the switch is yet to be determined, and there are several options for that (Block & Zakay, 1995).

Humans are more flexible than animals in timing behavior. Thus, while animals are dependent on well learned intervals represented in the reference memory, humans entertain more freedom in that respect. Rodriguez-Girones and Kacelnik (1994) found that absence of reference memory does not impair the scalar property in humans in a bisection task. When a subject is required to reproduce an interval's duration, the count of signals representing the duration of that interval as experienced by the subject, might be represented in the reference memory and during the reproduction phase the ongoing count of pulses can be compared to the reference memory until a match is achieved. In other temporal tasks, the reference memory might not be used.

The proposed model has the merits of being parsimonious while enabling scalar-timing properties as well as explanations of complex human-timing behaviors. Nevertheless, the model must be validated empirically by testing both scalar properties of human-timing behavior and the necessary properties of the attentional-gate.

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