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Chapter 9

Psychological Time and the Processing of Spatial Information

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A static "snapshot" of the world contains abundant information that allows the brain to automatically generate a reasonably accurate representation of geographic space in the area proximate to the observer. The sensory-perceptual systems of the brain automatically extract information that serves as raw material for psychological representations of geographic space. The classic view of visual perception holds that changes in sensory information that occur as a result of motion in the environment or of the observer (e.g., motion parallax) merely add additional cues concerning space to those available in a static display. This classic view is incomplete. As a person interacts with the environment, he or she encodes additional spatial, as well as temporal, information into memory. This occurs as a result of the controlled, or nonautomatic, processing of information. In short, some information is innately available to the organism, some becomes automated only as a result of learning, and some is only available if a person engages in controlled information processing. Eventually, high-level cognitive factors such as judgmental heuristics influence the use of all encoded spatial and temporal information.

Many studies on psychological time use the term *time perception*, and the bibliographic database *Psychological Abstracts* even uses it as a descriptor term (along with *time estimation*). Nevertheless, Gibson (1975) noted that "there is no such thing as the perception of time, but only the perception of events and locomotions" (p. 295). People do not directly perceive time; no special sense organs mediate human temporal experiences. Each organism is, however, "at any given moment, tuned to resonate to the incoming patterns that correspond to the invariants that are significant for it" (Shepard, 1984, p. 433). What are these ecologically significant patterns, or invariants—what Gibson (1966) called *affordances*—to which a person tunes when he or she experiences time? Gibson (1975) argued that "a sequence of external stimuli . . . provide[s] a flow of change, and it is this we perceive rather than a flow of time as such" (p. 299). He added that "the observer perceives both what is altered and what remains unaltered in the environment" (1975, p. 298). What is altered or changed is most critical for temporal experiences. Subjects use information concerning changes in the flux of sensory information in a relatively automatic way to establish fundamental representations of psychological time (Fraisse, 1963). The physicist Mach

(1942) commented: "It is utterly beyond our power to measure the changes of things by time. Quite the contrary, time is an abstraction, at which we arrive by means of the changes of things" (p. 273).

Cyclic and successive changes occur against a background of relative stability of geographic space. Most objects in a person's environment—mountains, buildings, walls, furniture, and so on—are unchanged for relatively long periods. Against this background, significant events occur: weather, inanimate objects, and animate objects all change in more or less predictable ways. These changes take place in an ordered sequence. Successive changes provide a source for the common spatial representation of time's passage, a straight line being steadily drawn in one direction.

Development of Temporal Information Processing

The sensory and perceptual systems subserving human spatial information processing are relatively well developed at birth. The nervous system automatically constructs a representation of nearby space, mostly as a result of visual feature analysis that relies on classic cues such as interposition, binocular disparity, and relative size. Gibson (1966) argued that various cues concerning distance are so important in the ecology of the developing organism that the visual system directly *picks up* information that the environment affords; it does not need to *process* it. Thus, observers perceive some spatial attributes (e.g., distance of an object, depth of a surface) directly as a consequence of the neurophysiological organization of the sensory systems.

The nervous system of very young animals also responds differentially to many temporal attributes. Human infants discriminate different phonemes, or elementary speech sounds, as well as changes in the rhythm of sounds (for reviews, see Lewkowicz, 1989 and Friedman, 1990). However, organisms acquire much of the information that they use to construct psychological time only with the involvement of learning and the use of controlled processes. Thus, temporal information processing heavily involves memory and cognitive systems as well as sensory and perceptual systems. These memory and cognitive systems mature relatively late.

Acquisition of temporal concepts such as simultaneity and duration relies on less developmentally complex concepts concerning movements, space, and distance. In his seminal work, Piaget (1969) investigated infants' and children's knowledge about time. His studies show that the development of temporal concepts progresses through several stages. The earliest awareness of time relies on the infant's developing ability to process information about consequences of its actions. Thus, the representation of time initially involves a procedural memory system. By the end of infancy, the child can plan an orderly series of movements in space, as well as recall an external series of events. However, children acquire an adult-like concept of temporal extent (duration) only much later in development, at about the age of 7 or 8. Piaget asked children to observe partially overlapping pairs of events and then make various temporal judgments. In one experiment, two mechanical snails moved across a table at different speeds. Piaget then asked them questions such as "Which snail started first?" and "Which snail was moving for a longer time?" He found that spatial characteristics of the situation influence children's duration judgments. If both snails start and stop simultaneously but travel different distances, children younger than 7 or 8 think that the snail that traveled a greater distance stopped later and traveled for a greater duration. Thus, young children apparently infer temporal concepts such as duration from spatial information such as distance traveled. This influence of space on psychological time persists in adults.

The Logic of Temporal Relationships

Processing of information about an event always depends on processing of information about other events occurring in close spatio-temporal proximity to it. Allen and Kautz (1985) proposed that "our perception of time is intimately connected (or identical to) our perception of events" and that "time (or events) appears to be hierarchically organized" (p. 253). They discussed 13 primitive terms that form the basis for all knowledge about the logical relationship between the time periods during which any two or more events occurred. These relationships are *equals, before/after, meets/met by, overlaps/overlapped by, starts/started by, during/contains, and finishes/finished by*. For example, if we say that event Y *finished* event X, we are asserting that (1) the interval in which X occurred began before the interval in which Y occurred, and (2) the interval in which X occurred ended simultaneously with the interval in which event Y occurred

Research on psychological time has mainly studied the *equals, before/after, meets/met by,* and *during/contains* relationships (Block, 1990; Block and Patterson, 1994). The *equals* relationship is investigated by asking subjects to judge simultaneity or successiveness. The *before/after* relationship is studied by asking subjects to judge the temporal order of successive events. The *meets/met* by relationship is the limiting case of a *before/after* relationship, in which two events occur successively with no interstimulus interval. The *during/contains* relationship is usually investigated in memory studies by asking subjects to judge which of two episodes (sequences of events) contained a particular event. Evidence that people can make such judgments with some degree of accuracy, even under incidental learning conditions in which they are not forewarned, suggests that encodings of environmental stimulus events routinely include temporal and other contextual information (see below).

Characteristics of Psychological Time

Many factors influence psychological time. Several distinctions are particularly important: (1) the aspect of time studied, such as position (i.e., temporal order of events) and extent (i.e., duration of an event); (2) the memory system primarily involved, usually either the episodic-memory system (personal experiences) or the semantic-memory system (general knowledge); and (3) the outlook of the observer, who may either be informed (prospective paradigm) or uninformed (retrospective paradigm) about subsequent temporal judgments. I will use these three major distinctions hierarchically to organize the present review.

Information about position: temporal order

Temporal order in episodic memory. Evidence reveals that temporal order (*before/after and meets/met by*) relationships may be stored in memory as a byproduct of the relatively automatic encoding of contextual information along with the memory representation of an event (Hintzman and Block, 1971, 1973; Hintzman et al., 1973, 1975). Friedman (1993) recently reviewed several kinds of theories on temporal dating of memories. There is little support for the notion that subjects judge the relative recency of an event by assessing the distance between it and the present. There is considerable support for location-based processes, especially for the notion that people encode aspects of the cognitive context prevailing at the time of an event along with the event itself. This information includes salient features of the environmental context (i.e., spatial context of the experience). A person may judge the relative order of events by relying on this contextual information. Because much of this information is automatically encoded, intentions or strategies (i.e., the prospective/retrospective distinction) usually have relatively little effect on temporal order judgments.

Several researchers have found that landmark events influence temporal order and other kinds of position judgments: People can more accurately date events that surround landmarks than those that do not (Hintzman and Block, 1971; Hintzman et al., 1973; Loftus and Marburger, 1983). Landmark events differ considerably from other kinds of events. As a result, they attract considerable attention (processing resources), and the encoding of them engenders considerable change in cognitive context.

Temporal order in semantic memory. Most experiments on temporal order relationships have been episodic-memory experiments; that is, people personally experienced events in a certain order, then they made temporal memory judgments about them. However, some temporal order information is encoded in memory in a more purely semantic way, that is, it is not necessarily encoded into the person's episodic-memory system in the corresponding temporal sequence. The semantic-memory representation of *A before B* is not necessarily established by first encoding a representation of A, then encoding a representation of B (Dennett and Kinsbourne, 1992). An example is the sentence, "People living in northeast Asia migrated to North America after an ice-age created a bridge across what we now call the Bering Strait." Sometimes, especially if there are several events, this process may be fraught with cognitive difficulties and ambiguities. People often have difficulty inferring the temporal order of events, as in the sentence, "Until it collapsed, the village's rock wall saved many of the buildings from damage by some of the larger floods to hit the area."

Information about extent: temporal duration

Temporal duration in episodic memory. Consider now the processes involved in encoding and remembering information about the duration of an event or episode. Several studies have compared prospective and retrospective duration judgments. The operational distinction is whether a person knows beforehand that he or she will be asked to judge duration (prospective paradigm) or only learns this after the duration has occurred (retrospective paradigm). Different factors influence the two kinds of judgment: the amount of attention allocated to processing temporal information lengthens prospective judgments, whereas the amount of change in other kinds of contextual information (e.g., environmental context) influences retrospective judgments (Block, 1992).

Subjects usually judge the first of two equal durations as being somewhat longer in duration, a phenomenon referred to as a *positive time-order effect.* Changing the environmental context (e.g., room) that prevails during the second of two durations eliminates the time-order effect (Block, 1982). It is also eliminated if changes in emotional context that might ordinarily have occurred during the first duration occur instead during a preceding experimental task (Block, 1986). Thus, we can attribute the typical finding of a positive time-order effect in remembered duration to the greater contextual changes that ordinarily occur during the first of two durations. The encoded cognitive context apparently changes much more rapidly as a person initially experiences a particular situation than it does later.

Temporal duration in semantic memory. To my knowledge, no one has studied duration judgment of events stored only in semantic memory—that is, not personally experienced. This kind of experiment should investigate judgments concerning events that have no obvious durational association (e.g., the most recent glaciation of northern North America), instead of judgments concerning events that do (e.g., the presidential term of Ronald Reagan). It would be interesting to see whether judgments involving such duration information involve processes similar to those involving other kinds of information, such as size or distance.

Spatial Influences on Psychological Time

Some of the most basic perceptual processes involving spatial locations of events influence psychological time. For example, if two brief events (e.g., visual stimuli) occur in different spatial locations, a person can usually correctly judge the temporal order of them if they are separated by several milliseconds; but if a person attends to a particular spatial location, an event occurring there may seem to occur up to 50 milliseconds earlier than an event occurring in a nonattended location. Most of the influences of space on psychological time, however, involve memory and cognitive processes more heavily than they involve perception and attention. Several studies have explicitly focused on how these processes influence psychological time.

Imagined activity in small-scale spaces

DeLong (1981) asked subjects to imagine performing activities in scale-model spaces for a duration that they estimated to be 60 minutes. Mean production of the 60-minute duration was about 5 minutes in a 1/6-scale space, about 2.5 minutes in a 1/12-scale space, and about 1.5 minutes in a 1/24-scale space. These represent compression ratios of about 1/6, 1/12, and 1/20, respectively. DeLong concluded that temporal productions were shortened relative to clock time in the same proportion that the scale-model environment was compressed. Mitchell and Davis (1987) attempted to replicate DeLong's findings. Although they also found that smaller scale leads subjects to shorten their productions relative to clock time, the effects were not nearly as dramatic as DeLong's. Compression ratios varied between about 1/1 (i.e., nearly veridical production) and 1/1.4. If the scale decreased considerably, this effect on productions disappeared or even reversed. Mitchell and Davis suggested that the effect of time compression depends on differences in the density of information processed in different scale environments and that there may be an optimum value for information density related both to scale and to environment type. One problem with these studies is that there is no 1/1 or other appropriate control condition. Interpretation of the findings remains problematic.

Physical activity in real spaces

Several other researchers have investigated retrospective duration judgment following actual physical (rather than imagined) activity in real environments. For example, Herman et al. (1983) had children and adults walk a straight-line distance through a normal-scale environment containing various objects. They then asked subjects to estimate the duration of each half of the walk and to estimate the distance between objects seen along the walk. The findings suggested that subjects tend to relate time and distance judgments in distance-estimation tasks (see later).

Temporal Properties of Spatial Representations

Recent research reveals several ways in which the mental representations of spatial information display intrinsically temporal properties. In addition, some of the same factors influence perception of space and memory for space (Thorndyke, 1981).

Information about position: spatial location

Information about the spatial location (relative position) of objects in space is apparently encoded into memory as a representation of Euclidean space. Researchers usually call this representation a *cognitive map*; it is a person's model of the world, or part of it. Cognitive maps contain information about objects and their relationships in space—that is, information that preserves spatial relationships within and among objects. There is continuing controversy on the issue of whether such information is represented in analog images, propositional strings, both, or some other kind of structure (see, e.g., Golledge, 1987; McNamara et al., 1989). Regardless of the form of representation, it is clear that representations of objects frequently include temporal properties and relationships. For example, perceptual representations preserve dynamic properties of objects, thereby containing integrated spatial and temporal information (Freyd, 1988, 1992).

Research on spatial orientation shows effects of what are variously called *landmarks, reference points*, or anchor points similar to effects on psychological time (Sadalla et al., 1980; Pick et al., 1988; Presson and Montello, 1988). The notion of an anchor point in spatial cognition is similar to that of a landmark, except that an anchor point is somewhat more personal (Couclelis et al., 1987). An anchor point is an environmental object, or cue, that is especially salient or distinctive to an individual. People use anchor points to coordinate spatial knowledge represented in their cognitive maps. This knowledge presumably includes procedural-, semantic-, and episodic-memory components. Couclelis et al. assumed that anchor points are organized hierarchically according to their relative salience. Children and adults show good recognition of spatial anchor points (Doherty et al., 1989). The anchor-point hypothesis of spatial cognition proposes that anchor points function as cues for organizing information in cognitive maps, thereby structuring a person's spatial orientation (Couclelis et al., 1987).

Information about extent: spatial distance

Similar kinds of variables influence estimations of space (i.e., distance traversed) and estimations of time (i.e., duration experienced). One of the most basic is that people usually overestimate relatively short distances or durations and underestimate relatively long distances or durations. Thus, distance judgments are a power function of actual distance (Cadwallader, 1979; Thorndyke, 1981), just as duration judgments are a power function of actual duration (Eisler, 1976). In many situations involving either distance or duration, the exponent of the power function is approximately 1. Spatial distance estimates lengthen as the number of intersections—that is, the number of distinct objects segmenting the traversed route—increases (Sadalla and Staplin, 1980a, b). Thorndyke (1981) found that map clutter—that is, the number of intervening points along a route—lengthens distance judgments. He proposed a model in which subjects perceptually scan a route (or an image of a route) and infer distance based on the (presumably, subjective) duration of the scan. Similarly, duration judgments lengthen as the number of distinct events segmenting the duration increase (Poynter, 1983). Thus, remembered duration may be an inference or construction based on the number of high-priority events or contextual changes remembered. These findings are remarkably parallel in nature, suggesting that at least some of the same memory and judgment processes underlie both phenomena.

People judge attributes, whether spatial or temporal, by using heuristics such as availability of relevant objects or events (Tversky and Kahneman, 1973; see also Kahneman et al., 1982). In judging either traversed distance or experienced duration, highly salient landmarks or anchor points serve hierarchically to segment the experience, thereby also providing a source of contextual changes. Although much evidence reveals that duration and distance judgments are closely related (e.g., Herman et al., 1983), other evidence suggests that distance judgments also rely on nontemporal heuristics, such as spatial imaging strategies (e.g., Lederman et al., 1987).

As noted earlier, research on duration judgments reveals that it is important to distinguish between prospective and retrospective judgments. To my knowledge, research on spatial information processing has not yet systematically explored this kind of distinction: there is no substantial body of studies comparing intentional (prospective) and incidental (retrospective) processing of spatial location or distance information. An exception is the work of Thorndyke (1981), who found that judgments of distances on memorized maps did not depend on whether subjects knew in advance about the task.

In the semantic realm, people often effectively transmit spatial information in a temporal way. Suppose one were to ask, "How far is it from Lake Arrowhead to Long Beach?" A perfectly reasonable reply is, "About 2 hours, perhaps longer during rush hour or bad weather." This information is usually more useful than that contained in a reply in spatial terms, "About 70 miles."

A Contextualistic Model

A contextualistic model of temporal experience, with only minor modification, can easily describe factors involved in the processing of spatial information. It proposes that several different kinds of variables interact to influence duration and other kinds of temporal experiences, behaviors, and judgments (Block, 1985, 1989a, 1989b, 1990). These general kinds of variables include characteristics of the experiencer (e.g., personality, cultural background, temporal outlook), contents of the time period (e.g., many vs. a few events), activities during the time period (e.g., active vs. passive processing of information), and temporal behavior (e.g., varieties of estimation). We need only a slight modification to transform the model into one of psychological space rather than psychological time. The four interacting kinds of factors critical for experiencing space are characteristics of the experiencer, objects in space, activities in space, and methods of assessing spatial behavior. Table 9.1 lists specific examples of variables representing each of these factors.

The contextualistic model is, of course, merely a general reminder of the kinds of factors that interact to influence the nature of the experience; it is not a detailed process model. Process models—specific, formal characterizations of how various factors interact—need to be developed to explain influences on spatial experiences and judgments in any particular spatial situation or task. The contextual-change model (Block and Reed, 1978; Block, 1990) is a more detailed process model that proposes how several factors interact to influence duration judgments. A similar process model might usefully characterize spatial distance judgments.

Table 9.1. Some specific examples of four kinds of factors that interact to influence spatial experiences, behaviors, and judgments.

Characteristics of the Experiencer
- Species (e.g., species-specific spatial orientation processes)
- Sex
- Age
- Personality
- Set (e.g., prospective or retrospective paradigm)

Objects in Space
- Simple, artificial environments (e.g., scale models)
- Artificial spatial representations (e.g., maps, charts)
- Complex, natural environments
- Familiarity with environment

Activities in Space
- Free exploration of space
- Constrained exploration of space
- Passive viewing of space
- Passive listening to verbal description of spatial information
- Processing strategies

Methods of Assessing Spatial Behavior
- Active reproduction (e.g., pathfinding)
- Symbolic reproduction (e.g., drawing or sketching)
- Verbal reproduction (e.g., recalling or reconstructing)
- Distance estimation (verbally or numerically)
- Direction estimation (verbally or manually)

Conclusions

The processing of spatial information and the processing of temporal information both involve relatively automatic processes and relatively controlled processes. Psychological time, especially the notion of duration, relies initially on perception of spatial information, such as concerning traversed distance. In adults, psychological time and psychological space are mutually interacting constructs that are influenced by some of the same factors and that rely on some of the same judgmental heuristics. Cross-fertilization of research on spatial and temporal information processing is likely to be extremely valuable. A contextualistic model of temporal experience may also be a useful model of spatial experience.

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