Space and Time in Perception and Action

EDITED BY

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SPACE AND TIME IN PERCEPTION AND ACTION

What is the instantaneous position of a moving object from the point of view of the observer? How does a tennis player know when and where to place the racket in order to return a 120 mph serve? Does time stop sometimes and go faster at others? Space, time, and motion have played a fundamental role in extending the foundations of nineteenth- and twentieth-century physics. Key breakthroughs resulted from scientists who focused not just on measurements based on rulers and clocks, but also on the role of the observer. Research targeted on the observer's capabilities and limitations raises a promising new approach that is likely to forward our understanding of neuroscience and psychophysics. *Space and Time in Perception and Action* brings together theory and empirical findings from world-class experts and is written for advanced students and neuroscientists with a particular interest in the psychophysics of space, time, and motion.

ROMI NIJHAWAN is a Reader in Psychology at the University of Sussex, UK. In 1994, he introduced the phenomenon and the term "flash-lag effect." He continues to study its implications for the interaction of the animal with the environment.

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Contents

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Space and time: the fabric of thought and reality

BEENA KHURANA AND ROMI NIJHAWAN

> Space and time are modes by which we think and not the conditions in which we live.
>
> – *Albert Einstein*

Since the beginning of sentience, the fabric of reality has been the subject of intense curiosity, and the twin concepts of *space* and *time* have figured prominently in the thinking of individuals of various intellectual persuasions. Understanding in science has advanced significantly through the postulates that underpin coherence and precision in the representation, and measurement, of space and time. These advances have formed the bedrock of the development of many disciplines. However, until the latter half of the nineteenth century many properties of space and time were assumed and therefore remained unquestioned. For example, the implicit acceptance of concepts such as *absolute space* (a coordinate system at rest, relative to which all inertial frames move at constant velocity) and *absolute time* (a universal time independent of any "clock" or mechanism) made most issues related to space and time impervious to empirical investigation and theoretical debate. This state of affairs was robustly challenged by scientists such as Ernst Mach, who among others imagined observers equipped with measuring devices (rulers and clocks) arriving at concepts at odds with notions of absolute space and absolute time.

Many well-known scientists whose work spanned the latter half of the nineteenth century (Mach included) crossed the disciplinary boundaries of physics, philosophy, and vision science. In Mach's thinking on space and time, the observer's sense perception played a critical role. Mach (1890) wrote: "The facts given by the senses . . . are the starting-point and the goal of all the mental adaptations of the physicist [and] the source of every hypothesis and speculation in science." This statement is reminiscent of another by von Helmholtz (1867): "Apprehension by the senses supplies . . . directly or indirectly, the material of all human knowledge . . . there is little hope that he who does not begin at the beginning of knowledge will ever arrive at its end" (cited in Warren & Warren 1968). It is noteworthy that, although in the new conception of space and time to emerge in the early part of the twentieth century the observer played an integral role, the meaning of the term "observer" remained obscure. Thus, although it was implicit that the observer's nervous system was part of the causal framework, one may ask: Which component(s) of the nervous system

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are relevant? It is amply apparent that a deeper understanding of space and time, from any point of view, will require a more complete understanding of the observer's nervous system. We suggest that sensory and motor processes in particular not only involve neural representations related to space and time but, more critically, form the basis of the scientist's conception of space and time.

One change apparent in postrelativity thinking is that space and time are no longer thought of as distinct dimensions (Minkowski 1908). We believe it is time for a critical review of separate treatments of space and time in neuroscience and psychophysics. Our unifying efforts are akin to previous efforts by scientists to remove the sharp boundary that is often assumed to exist between perception and action. From a biological standpoint, change and its detection are crucial to the animal's survival. We contend that change, or more generally spatiotemporal events, are the most important stimuli for the nervous system, so it is natural to think of space and time within a unifying perspective.

Change, its detection, and an appropriate response to it are crucial features of all animal behavior. For a single-celled organism, detection of change in the concentration level of some chemical is key to survival. The goal of both internal processes within the animal and its overt behavior in the environment is to maintain homeostasis. For multicelled organisms, change is frequently associated with movement, either because the change itself is due to movement in the environment or because the animal must respond to change with movement. Furthermore, it is well established that change, or any spatiotemporal discontinuity, is a potent stimulus for animal nervous systems. For example, critical information about objects is available at color or luminance edges; stimulus onsets and offsets cause neurons to respond vigorously, whereas static stimuli frequently do not produce a neural response at all, particularly in immature nervous systems; retinal image stabilization (i.e., removal of change) causes visual percepts to disappear rapidly, and so on. Thus, even from a biological standpoint, space and time are naturally connected, and the sharp (intuitive) divide between the two is misleading. It is interesting that a unification of space and time from the point of view of neuroscience and psychophysics seems linked to a unification of perception and action already suggested by a number of notable scientists (e.g., Sperry 1952; Rizzolatti et al. 1997). In conclusion, space and time are connected if one considers moving bodies and clocks from a physical perspective, and when one considers the most significant type of stimulus for biological systems, namely change.

Traditionally, psychologists and neuroscientists treat problems concerning *space* and *time* as more or less two separate and independent problems for investigation. For example, in David Marr's seminal book *Vision,* the spatial aspects of vision were given considerable coverage in stark contrast to the limited analysis accorded to the dimension of time. This is partly because visual pathways are geared to the processing of spatial dimensions. For example, in the domain of space, hyperacuity-level performance (Westheimer 1979) in the two-dimensional plane and in depth appear unrelated to time. Temporal hyperacuity has also been reported (Rose & Heiligenberg 1985). However, such levels of responsiveness require integration over space *and* time. So, the dimension of time is part and parcel of sensory processes even when its role is not apparent or explicitly investigated. Ironically, integration processes that support many types of performance by sensory systems, hyperacuity included, are themselves slow. The large latency of visual processes has been reported time and again (Aho et al. 1993).

On the other hand, of the many articles and books published on the topic of time, few give due consideration to spatial dimensions. One reason for separate empirical investigations of space and time could be that the spatial analysis of events on the one hand, and the timing of events on the other, is carried out by highly distinct mechanisms in the brain. The most natural way to analyze the problem of space is in terms of topographic mapping of the receptor epithelia onto the surfaces of both subcortical and cortical structures, whereas the mechanisms that underlie temporal processing of events may be highly varied. For example, timing mechanisms may be localized in cerebellar processes, motor networks involving the frontal cortex, parietal networks, or some combination thereof. Disparate networks responsible for temporal processing are engaged as a function of the task at hand, with different tasks requiring different networks. These processing differences between space and time may limit an integrated treatment of the two.

Nonetheless, there are important justifications for positing that a unified treatment of space and time is both timely and fruitful. For example, many scientists hold that vision cannot be separated from action, and although vision is often discussed without regard to time, action certainly cannot be similarly divorced from time. There is another aspect to considerations of the dimension of time in vision. Visual perception is not instantaneous; time makes its presence felt in visual processing, particularly because there are significant neural delays at the level of phototransduction and the transmission of receptor signals to the primary visual cortex and beyond. These delays have obvious implications for sensory processes engaged with dynamic visual events and for the motor system's ability to utilize the output of these processes for action. Where change is associated with movement in the visual environment, as is frequently the case, neural delays or issues of time directly impact issues of space. Thus, the relevance of time for vision, already well established for research on auditory processes, is beginning to be appreciated.

A unified treatment of time and space is apparent in the list of chapters. One chief methodology employed by researchers to address problems of space and time involves the study of "illusions," particularly when these illusions are related to or caused by actions. It is well known that animals such as humans are subject to a number of "illusions" related to dimensions of space and time. Action related to perception is thus liable to potential errors unless one takes the strict position that parallel neural streams subserve perception and action. It is doubtful, however, that the two streams are completely independent of each other. In the recent past, researchers have identified and scrutinized several important "illusions." The sixty-four-thousand-dollar questions are: Can the nervous system compensate for these illusions to produce accurate behavioral output? Does the nervous system need to compensate for these illusions, or do these illusions actually aid in the production of adaptive behavior? These questions have become more central to the work on space and time in the last several years. Research conducted in response to such questions is the mainstay of this book.

We bring together theoretical treatments and empirical findings from a number of neuroscientists and psychophysicists with significant experience in the study of space and time. The twin issues of localization in space and time are covered in this book. Two conferences on the topic of Space–Time were key to providing a wellspring of ideas from which this book took shape. The first was titled "Visual Localization in Space–Time" and was held at the University of Sussex (August 2002); the second focused on "Problems of Space and Time in Perception and Action" and was held at the California Institute of Technology (June 2005), as part of the proceedings of the annual conference of the Association for the Scientific Study of Consciousness (ASSC 9). We seek to capitalize on the many fruitful areas of investigation that have emerged in the past several years, and bring together the approaches of scientists who treat time and space as two faces of the same coin (see, e.g., Schlag & Schlag-Rey 2002). The thinking and experiments of researchers working on these topics are presented in a single volume to encourage greater synergism in this exciting field of investigation. This book will achieve its goal if it challenges scientists to bring future questions on space and time under a common umbrella of investigation.

Given that perception is not instantaneous, logic dictates that real-time action must acknowledge and overcome delays inherent in the nervous system. Therefore, we begin with action and the requisite computations of space and time for accuracy in action. Interrogating visual stability in the presence of eye movements has offered insight into the representation of visual space. The late Hitoshi Honda (Chapter 3) deftly analyzes the texture of visual space surrounding a Saccadic eye movement in the presence and absence of visual input. Memory is presented as a cocontributor to vision in maintaining a stable visual world (Lappe, Michels, & Awater, Chapter 4). Using Saccadic eye movements, a case is made for sensorimotor control that requires representations of *both* space and time (Schlag & Schlag-Rey, Chapter 2), whereas a breath of fresh air for psychophysics is presented by the relativistic-like effects of spatial compression and time dilation as a result of shifting gaze (Morrone, Ross, & Burr, Chapter 5). Matin and Li (Chapter 6) make the argument for stability based on a quantitatively precise cancellation function between retinal input and extraretinal position information and the elimination of presaccadic persistence. However, because the underestimation of eye deviation renders compensation via extraretinal signals incomplete, it is provocatively proposed that extraretinal signals are not in the service of compensating prior retinal signals but actually destroying them (Bridgeman, Chapter 7).

What about seeing for reaching? Evidence is sought but none found for object pursuit producing "spatial advanced" representations for overcoming neuromuscular delays (Brenner & Smeets, Chapter 8). At the close of this section the relationship between visual motion and goal-directed reaching is reviewed to conclude that visual motion, although shown to compromise the accuracy of goal-directed reaches, can also contribute to accurate reaching behavior (Whitney, Murakami, & Gomi, Chapter 9).

These initial chapters pivot around representations for action. They are then followed by two sets that focus on temporal and spatial phenomena in perception. We begin with those focused on temporal processing. Going backward in time, a.k.a. temporal antedating, is offered as an account of saccadic chronostasis, or the perceived temporal lengthening