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Finding time

Peter R. Killeen*

Department of Psychology, Arizona State University, Box 1104, Tempe, AZ 85287-1104, United States

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ABSTRACT

We understand time through our models of it. These are typically models of our physical chronometers, which we then project into our subjects. A few of these models of the nature of time and its effects on the behavior of organisms are reviewed. New models, such as thermodynamics and spectral decomposition, are recommended for the potential insights that they afford. In all cases, associations are essential features of timing. To make them, time must be discretized by stimuli such as hours, minutes, conditioned stimuli, trials, and contexts in general. Any one association is seldom completely dominant, but rather shares control through proximity in a multidimensional space, important dimensions of which may include physical space and time as rendered by Fourier transforms.

Contents

1. Introduction

> The senses provide us not with a picture of the external world but with a model of it. They serve not to achieve verisimilitude (whatever that might be) but to facilitate our interaction with it. (Treisman, 2006, p. 222)

* Tel.: +1 480 967 0560.
E-mail address: Killeen@asu.edu

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Time and association are the central concepts of this symposium. Both carry heavy burdens of connotative meaning. Their meanings are entangled. For events to be associated they must share, it is said, a certain relationship in time. For time to manifest, it must be associated with events. A respected approach to untangling difficult conceptual issues, such as wave-particle duality, is to adopt the school of thought called "shut up and calculate". In behavioral psychology, its operant avatar is "shut up and reinforce". The reaction to this paper from some readers will be an even more parsimonious school of thought, "shut up and go away". This is because its contents will be most easily understood as non-sense, to those whose sense of sense has been schooled in the schools from which we all have matriculated. Those who take time to consider the ideas are welcomed as associates on this strange voyage in search of time.

1.1. Mathematical vs. common time

If you are asked to define time, your definition would probably resonate with Newton's postulate: "true and mathematical time flows equably without regard to anything external, and by another name is called duration". This is our culture's default model of time. Its conjugate, relative or common time, is known directly, by sensible externals, moves unequably, and with duration measured in terms of the change in location of objects—in terms of motion. To which time does the title of this symposium refer, mathematical time, or common time? If the former—absolute, true, and mathematical time—where is it to be found? In mathematical equations? In those, time is the argument; infinitesimal changes in it are the denominators of physics' multitude of differential equations. Time is always the thing with-respect-to-which change is evaluated; always the stage, seldom the play, and never the actor, for things only happen in time, not because of time. Nothing in physics says that time flows, except Newton's singular postulate that it does. But what are the banks and bed of that river? Which way does it flow? Does it meander? Nothing in basics physics requires t_2 to come after t_1 (although the principle of least action does require smooth monotonic flow). We arrange things that way on a graph, whenever that makes them look simpler. Physics does not tell us how to get from t_1 to t_2: "Just wait, and it will surely happen" is the best any physicist might do.

Perhaps we can find true time in the vibration of cesium atoms, humming in unison at the national bureau of standards. There, on an office wall we may find a graph and caption that looks like that in Fig. 1.

Three things are notable about these data: (1) time is measured by means of recurrent motion; (2) the motions are not equable: their periods support error bars, and drift over days; (3) measurement does not include allowance for the linear frequency drift of the ensemble. Our best current standards thus measure common time. What then is mathematical time, and is it relevant to psychology? Mathematical time is a hypothetical construct, which, along with absolute space, constitutes the framework of classical mechanics, wherein "time is defined so that motion looks simple" (J. A. Wheeler, cited in Doughty, 1990, p. 29). In its modern guise, however, it is less commonsensical than common time. This is because we commonly think of true time as linear; or if not linear, at least a monotone dimension along which we can order events. But Einstein showed that mathematical time does not itself flow equably: The period of a clock dilates with the clock's velocity relative to a stationary observer. He showed that the concept of "simultaneous" is incoherent across distance; and that the temporal sequence of two events can be different for different observers. In sum, mathematical time is intrinsically dependent on the position and motion of an observer, and thus different for every observer. t_2 does not always come after t_1.

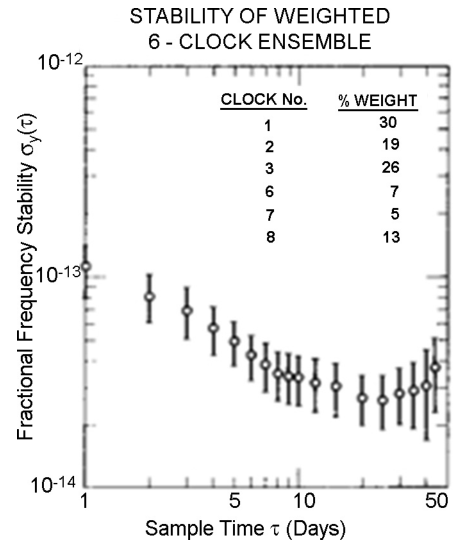

Fig. 1. Reproduced from Allan et al. (1972), shows the best contemporary approximation of common time to mathematical time. Reproduced with IEEE's permission and payment.

Common time is based on motion. Sometimes the motion is linear, as sand or water through apertures. But most often time is abstracted from periodic motion, from oscillations. Indeed, even the hourglass must be periodically inverted, and water clock periodically refilled; and it is at those turns that information is concentrated, associations made. The rotation of the earth gives days, the revolution of the moon gives months, and the revolution of the earth around its common center of gravity with the sun gives seasons and years. But gravitational interactions among these bodies affect earth's periods. The standard of ephemeris time is computed in such a way to minimize the errors in imputing a common underlying time to all these oscillations; time is thus derived as the principle component of celestial oscillations.

Division is always more difficult than addition. The length of Roman hours, based on the sundial's division of the day, varied with the seasons. Division of the year into months consistent with lunar cycles proved impossible, various attempts yielding the various calendric systems of extended time. By counting the oscillations of a pendulum, medieval church bells enforced a common, fallible time—for all within earshot. In recent ages, divers communities kept reliable local times, often at odds with the time of other nearby communities. In modern times reliability has been vastly improved by finding ever-faster oscillators and more accurate counters—and improved again by averaging ensembles of cesium oscillators. Common time is now the principle component of atomic oscillators. When it drifts sufficiently out of calibration with mundane yardsticks, the definition of one or the other—the year or the second or the clock—is then adjusted. Such common time has become essential for commerce, transportation, communication, and geodesy. Because of the expansion of the universe, with all other celestial bodies moving at different velocities than our solar system, it is disjoint from the time measured in other galaxies. Common time is an artifact, no less than mathematical time. But it is a directly, if diversely, measured artifact. "Absolute, true time" is inferred for use as the denominator for the rate equations of physics and chemistry, stipulated to make the mathematics consistent. What is important about common time is not that it approximates an absolute, true and mathematical time. On the contrary. What is important about it is that it is common. It is close to us, our perceptions, our behavior, and close to our community. It is what we evolved to sense as the stage upon which stance unfolds into action.