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View

Lost in time: a historical frame, elementary processing units and the 3-second window

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Abstract. The main topics of time and timing in psychology, cognitive neuroscience and biology have been formulated already in the nineteenth century. Unfortunately, time and timing as a challenging topic has been put to rest for quite some time, but has become a central issue again during the last years. It has become clear, that perceptual or cognitive processes can only be understood if the dimension of time is taken more seriously. The reduction of complexity in neuronal systems is for instance, achieved by temporal integration mechanisms which are independent of the content of a percept or a cognitive act but are presemantical operations. It is essential to distinguish between content functions and logistical functions that provide presemantically defined temporal frames for mental activity.

Key words: temporal perception, subjective present, complexity, reaction time, consciousness, perceptual identity

LOOKING INTO THE PAST: WHEN THE PRESENT CONCEPTUAL FRAME OF STUDYING TEMPORAL PERCEPTION WAS FORMED

It is easy to say where something is; it is much harder to tell when something happened. For the whereabouts we use coordinate systems that allow to indicate left and right using symmetry axes, and up and down using gravity. The whereabouts is effortlessly available; humans are spatial creatures with reliable sensory systems using primarily visual information. When something has happened, is much more difficult to determine, presumably because reference systems like symmetry or gravity are lacking. We have to refer to events with time tags – but what are events, and how are they generated in the brain? Whereas space is made available by external cues, time is accessible only by internal cues. No wonder that one easily may retract from an analysis of time, if external reference systems are not available. "*In te animus meus tempora metior*" – (I measure time in my mind) as St. Augustine said in the eleventh book of "The Confessions" (at the end of the fourth century) which can be considered until today as one of the deepest analyses of time ever written.

However, geophysical cycles like day and night, the annual rhythm, lunar phases or the tides may give external temporal references. But such cycles by themselves do not tell us when something has happened. We have to use numbers to count such regular events, i.e., an explicit mental operation is necessary, and a reliable memory system to monitor the passage of time, as for instance expressed in a calendar, has to be used. Thus, the access to what we refer to as time is much harder than the access to space. This may correlate with the observation that there are as many theories of time as there are authors who reason about time. Thus, we appear to be lost in time, or as one might say in a more positive way: time can be considered as the last frontier in the sciences.

The fundamental problems of time and timing in psychology and cognitive neuroscience have been formulated already during the sixties of the nineteenth century. It was the biologist Karl Ernst von Baer who came up with a notion of the moment, i.e., the shortest time interval of a living being. When he gave his talk in 1860 at the foundation of Russian Entomological Society in St. Petersburg, he left behind the concept that a moment is the timeless border between past and future, usually referred to as the "now". Von Baer made the point that different organisms may have different moments if measured with external means, namely clocks. The conceptual invention of the moment meant stepping out of the continuous flow of time as described by Isaac Newton in the foundation of classical physics ("*Principia Mathematica Philosophiae Universalis*"): "Absolute, true and mathematical time by itself and from its own nature flows equably without relation to anything external". The moment, as described by von Baer, is species-specific, and may have different physical durations in different animals; insects, snails, rats or humans are characterized by different moments.

Another important discovery on temporal experience came from the physicist Ernst Mach who was interested in the discrimination of different temporal durations. In studying differential sensitivity he observed that there is no experience of duration for intervals that are shorter than 40 milliseconds. Stimuli with 40 ms duration or shorter are experienced as "time points". On the basis of this observation one feels invited to use time points as discovered by Ernst Mach as the human moment hypothesized by Karl Ernst von Baer. This Machian time point can be seen as the temporal window for a primordial event which is a building block of conscious activity.

Today, almost 150 years later, almost every psychological laboratory uses measures of reaction time to look into the complexity and dynamics of mental processing. Chronometric analyses have become easy and unquestioned indicators for brain processes and cognitive activities. This experimental paradigm goes back to the Dutch scientist Karl Donders, who used simple and choice reaction time to get a better understanding for instance of decisions; his experiments started perhaps the most important success story in experimental psychology and cognitive neuroscience.

Whereas Karl Ernst von Baer, Ernst Mach and Karl Donders were looking at shortest or rather short temporal intervals, Karl Vierorth from Tübingen, was interested in the question how humans can reproduce the duration of longer temporal intervals. He observed that rather short intervals are reproduced longer than the stimulus, and longer intervals are reproduced shorter than the stimulus. This observation implies that between "long and short" there must be an interval which is reproduced correctly, usually referred to as "indifference point". The question came up whether this indifference point is an experimental artifact, or whether it reflects a basic neuronal process. Interestingly, both answers are correct.

If temporal intervals are chosen between one second and several seconds (e.g., five seconds), one observes an indifference point at approximately 3 seconds. This indifference point reflects a basic neuronal process of presemantic temporal integration (see below). It can however also be demonstrated that in other temporal regions indifference points occur which do not reflect an automatic temporal integration process, but are created by the specific experimental conditions. As has been suggested by the "adaptation-level theory" by Helson (1964) humans construct a reference point, if they are exposed in an experimental setting to stimuli of different intensity or different duration (Pöppel 1971). These reference points correspond to the geometric mean of all stimuli presented during an experimental setting. The ecological reason for the construction of such reference points might be that stimuli with higher probability should be processed with better differential sensitivity. Such a mechanism of temporal adaptation would imply the existence of a special temporal memory which is continuously calibrated by stimuli of different durations. Such a mnemonic system might be the basis for temporal impressions of something lasting long or short.

COMPLEXITY REDUCTION: HOW TIMELESS EVENTS AS MATERIAL BASIS FOR CONSCIOUS ACTIVITY MIGHT BE CREATED

One essential feature of perception or action is effortless availability; other than in cognitive processes like rational conjecture we have an effortless access to images, words, smells, memories, feelings or movements. Looking at the complexity of the neuronal representation of information, the easy and effortless availability of the basic repertory of conscious phenomena is rather enigmatic. Apparently the nervous system has developed strategies to overcome inherent problems of complexity. Where do these problems come from and how are they solved? There are several sources giving rise to complexity, namely the physics of stimuli, biophysical constraints in the transduction of stimuli, and their central representation.

One source of complexity comes from stimulus transduction which is principally different in the sense modalities like audition or vision, taking less than 1 ms in the auditory system and more than 20 ms in the visual system. Thus, auditory and visual information arrive at different times in central structures. Things become more complicated by the fact that the transduction time in the visual modality is flux-dependent, i.e., that surfaces with less flux require more transduction time at the receptor surface. Thus, to see an object with areas of different brightness or to see somebody talking, different temporal availabilities of local activities within the visual modality and similarly different local activities across the two involved modalities have to be overcome. If in addition somatosensory information has to be integrated to identify an object the integrating systems are confronted with even more temporal challenges as transduction time in the somatosensory system again is different (Pöppel et al. 1990).

For intersensory integration besides biophysical problems as given by the transduction times also physical problems have to be considered. The distance of objects is obviously never predetermined. Thus, the speed of sound (not of light) becomes a critical factor. Approximately at a distance of 10 m transduction time in the retina corresponds to the time the sounds require to travel to the recipient. Up to this "horizon of simultaneity" (Pöppel et al. 1990) auditory information arrives earlier in the brain; beyond this horizon, visual information is earlier. Again, there must be some kind of mechanism which overcomes this temporal problem.

Besides biophysical and physical aspects there is a further problem introduced by the specific brain architecture (Nauta and Feirtag 1986). As has been shown in neuroanatomical studies there is a large degree of divergence in the projection systems. It has been estimated that each central neuron innervates approximately 10 000 other neurons. This means that local information is spread out over a broad field of receptive neurons and because of the different transmission times along the axons, which is for instance based on the different lengths of axons this local information is not only distributed spatially but it is also spread out over time.

A further aspect of complexity is introduced by the mode of functional representation (Pöppel 1989). New experimental evidence using imaging technology like fMRI, MEG or PET indicates that each functional state is apparently characterized by a spatiotemporal pattern of modular activities. Different modules in the visual modality (being for instance responsible for color perception or facial recognition) and similarly in the auditory modality (being for instance responsible for the prosody or the semantics of speech) are co-activated.

Thus, not only on the cellular but also on the modular level the brain has to deal with integration of spatially distributed and temporally imprecise neuronal information.

How can complexity be overcome? In a radical cognitive approach (which in an epistemological sense would imply dualism) one could argue that there is no problem at all; the problems as described above are irrelevant as the amount of temporal noise (up to some tens of ms) is very small and on the basis of situational analysis the categorical definition of percepts follows a top-down-analysis in which input problems or representational specifics become irrelevant.

Alternatively, and this is my personal position, one can argue that the brain has developed specific mechanisms to reduce complexity systematically. There is abundant experimental evidence that such a mechanisms may in fact be at work (e.g., Pöppel 1997a). It is suggested that the problems mentioned above can be overcome if the nervous system uses stimulus-triggered neuronal oscillations. One period of such an oscillation may represent the formal basis of an elementary integration unit within which temporally and spatially distributed information is linked and united. Such units or system states are independent of the exact temporal occurrence of input data being atemporal and thus, creating co-temporal zones. There is plenty of experimental evidence for such systems in the time domain of 30 to 40 ms; evidence comes from single cell studies in the sensory and motor system, from studies on evoked potentials, from observations on reaction times or latencies in eye movements and from temporal order threshold.

A strong support for this conceptual notion is given by experiments with patients who have to undergo a general anesthesia (Madler and Pöppel 1987, Schwender et al. 1994). In this situation the oscillatory activity within the neuronal assemblies which represents such system states, comes to a stop, the result being that such patients process no sensory information at all (some of the patients report that no time has passed at all between the beginning of the anesthesia and the reawakening after anesthesia). This oscillatory process which is presumably implemented in the cortico-thalamic pathway provides a formal framework for complexity reduction, and it is believed to be the neuronal basis for the creation of „primordial events", i.e., the building blocks of conscious experience. Within this theoretical framework, the elementary integration units are also responsible for an effortless access of sensory information.

PERCEPTUAL AND CONCEPTUAL IDENTITY: WHAT THE PURPOSE OF A "3-SECOND WINDOW" OF TEMPORAL INTEGRATION MIGHT BE

On a next level of complexity reduction the primordial events identified on a lower level are linked together. Observations made within different experimental situations provide evidence of the operative importance of a temporal integration mechanism being essential to an understanding of consciousness. Although these observations have been made in different contexts a common underlying principle is detected in spite of obvious observational diversities. The "botanizing" attitude to look for common principles in different realms of activities is guided by the conviction that if a phenomenon shows up in qualitatively different experiments or situations a universal principle has to be suspected. In what follows an answer shall be given to the question of what the "state of being conscious" (Pöppel 1997b) could mean. The anchor point of the reasoning is that one can understand consciousness only if one analyzes temporal mechanisms of neuronal processes and behavioral acts.

The subjective present as a basic temporal phenomenon has interested psychologists for more than one hundred years (e.g., James 1890). We are now in a situation to indicate how long such a subjective present actually lasts. This numerical answer can be derived from a number of different experiments which all converge to a value of approximately 2 to 3 seconds. Support comes from different domains like temporal perception proper, speech, movement control, vision and audition, and also memory. All these observations suggest that conscious activities are temporally segmented into intervals of a few seconds and that this segmentation is based on an automatic (pre-semantic) integration process providing a temporal platform for conscious activity. It should be stressed that the temporal platform does not have the characteristics of a physical constant but that an operating range of approximately 2 to 3 seconds is basic to mentation; obviously, one has to expect subjective variability for such a temporal integration window.

What is the experimental evidence? If subjects have to reproduce the duration of either an auditory or a visual stimulus one observes veridical reproductions with small variance up to 2 to 3 seconds, and large errors of reproduction with a strong tendency for a shorter reproduction for longer intervals (e.g., Pöppel 1971, see also above). It appears as if short intervals can be experienced as a whole while longer intervals temporally disintegrate, i.e., during short intervals of a few seconds it is possible to focus one's attention on specific events.

Temporal integration can also be studied by subjective accentuation of metronome beats. One of the founding fathers of experimental psychology, Wundt (1911), pointed out that temporal grouping of successive stimuli has a temporal limit of approximately 2.5 seconds. In such a metronome task the subject imposes a subjective structure onto identical physical events. If auditory stimuli like click sounds follow each other with an interstimulus interval of for instance one second, it is easy to impose a subjective structure by giving a subjective accent to every second of the stimuli. If, however, the temporal interval between the stimuli becomes too long (for instance 5 seconds), one is no longer capable to impose such an apparent temporal structure. The two separate sequential stimuli no longer can be united to one percept, i.e. temporal binding for temporally adjacent stimuli is no longer possible because they fall into successive integration windows. In recent experiments with brain-injured patients it could be demonstrated that the temporal integration process as studied with this metronome paradigm is selectively impaired after injuries in frontal areas of the left hemisphere (Szelag et al. 1997). Patients with injuries in these areas adopt a new strategy of integration by consciously counting successive events; the "pop-up" impression of belongingness of successive tones is apparently lost in these patients and, thus, they reconstruct togetherness by abstract means.

A qualitatively different paradigm providing further insight into the integration process comes from studies on temporal reversal of ambiguous figures (Pöppel 1997a). If stimuli can be perceived with two perspectives (like a vase or two faces looking at each other) there is an automatic shift of perceptual content after approximately 3 seconds. Such a perceptual shift also occurs with ambiguous auditory material, such as the phoneme sequence "ku-ba-ku" where one hears either "kuba" or "baku"; one can subjectively not prevent that after approximately 3 seconds the alternative percept takes possession of conscious content.

This regular shift between two potential interpretations of the stimulus material has also been observed in studies on binocular rivalry; interestingly, the switching rate of the two potential interpretations of visual stimulus material is slowed down extremely after injury of cortical areas (Pöppel et al. 1978). The spontaneous alteration rate in the two sensory modalities, i.e., vision and audition, suggest that normally after an exhaust period of 2 to 3 seconds attentional mechanisms are elicited that open the sensory channels for new information. If the sensory stimulus remains the same, the alternative interpretation will gain control. Metaphorically speaking, every 2 to 3 seconds, the endogenously generated question arises "what is new", and with unusual stimuli such as the ambiguous material the temporal eigen-operations of the brain are unmasked.

Some data in a study by Sams and colleagues (1993) where the amplitude of the mismatch negativity as a function of the interstimulus interval (ISI) was investigated support the above considerations. The mismatch negativity, a component of the auditory event-related potential, is elicited by a physical deviant stimulus such as frequency or intensity of a tone in a homogeneous stimulus sequence. If during the experiment the ISI is altered, the largest amplitude of the mismatch negativity is observed with an ISI of 3 seconds, i.e., shorter and longer ISIs result in smaller amplitudes of the mismatch negativity. As negativity indicates increased neuronal activity, this result suggests that the auditory channel is characterized by a higher neuronal activity in regular intervals. This modulation is endogenously determined, being a property of the neurocognitive machinery itself, and it implies that approximately every 3 seconds the sensory channel is more sensitive than at other times for new information coming from the external or internal environment.

Temporal integration for intervals of 2 to 3 seconds is also seen in sensorimotor control. If a subject is requested to synchronize a regular sequence of auditory stimuli with finger taps, stimuli are anticipated with very small variance by some tens of milliseconds (Mates et al. 1994, Miyake et al. 2001). This kind of sensorimotor synchronization is, however, only possible within the operating range of a few seconds. If the next stimulus lies too far in the future (like 5 seconds) it is not possible to program an anticipatory movement that is precisely linked to stimulus occurrence; in such a case movements become irregular and subjects prefer to react to the stimulus instead of anticipating it. Observations on the duration of intentional movements coming from ethological studies gave similar numerical values (Schleidt et al. 1987). Members of different cultures including those from old ethnia (for instance Yanomami

Indians) show very similar temporal patterns for homologous movements the preferential duration being 2 to 3 seconds. On the basis of these human studies Gerstner and Fazio (1995) have observed in various species of higher mammals that they also tend to segment their motor behavior in the same temporal range as humans do. This observation suggests that we are dealing with a universal principle of temporal integration that transcends human cognition and behavioral control.

Supporting evidence for a specific temporal integration mechanism comes also from studies on memory and speech. In a classical study (Peterson and Peterson 1959) it was shown that the working platform for short-term retention is just a few seconds; only if rehearsal is allowed are we capable to store information for longer intervals. Experiments on the temporal structure of spontaneous speech on adults (Vollrath et al. 1992) and on children (Kowal et al. 1975) also show that spoken language is embedded in temporal windows of up to 3 seconds duration giving speech its rhythmic structure.

As the experimental and other observations referred to above employ qualitatively different paradigms covering perceptual processes in audition and vision, cognitive evaluations, movement control, speech, cultural artifacts, mnemonic representation, perceptual accentuation or temporal integration, it is proposed that temporal integration in the range of 2 to 3 seconds is a general principle of the neurocognitive machinery. This universal integration process is automatic and pre-semantic, i.e. it is not determined by what is processed, but it defines a temporal window within which conscious activities can be implemented. Because of the omnipresence of this phenomenon, it can be used as a pragmatic definition of the subjective present which is characterized by the phenomenal impression of "nowness". Temporal integration in the range of 2 to 3 seconds defines, however, also the singular "state of being conscious" or STOBCON (Pöppel 1997b). The 3-second-window provides a logistic basis for conscious representation, a working platform for our phenomenal present.

The access to this temporal operating platform is apparently controlled by independent neuronal mechanisms as the observations on phenomena like residual vision (also referred to as "blindsight") after brain injury (e.g., Pöppel et al. 1973) suggest. It has been observed that patients are still capable to process visual information although they report to be absolutely blind. This phenomenon can be interpreted as indicating a deficit with the entering operations into the temporal platform of conscious activity. If such an access mechanism to the temporal platform must be normally operative the question arises whether the content of the separate STOBCONs is always of the same nature, i.e. whether the access machinery to a conscious representation is just a passive bottleneck through which information has to be channeled to reach a temporal platform, or whether access mechanisms are characterized by selection processes. As there are in principle two qualitatively different contents of a STOBCON, one being experiential and one being reflective, it appears reasonable to assume that the access mechanisms are at the same time selection mechanisms. As these selection mechanisms remain implicit one has to conclude that the driving force of conscious activity still remains in the dark.

The purpose for the omnipresent 3-second time window within this conceptual frame is the creation of a time zone within which the identity of a percept or a thought is created and maintained, but that a new identity may enter conscious representation after the completion of this window. Only if temporal integration is automatic and presemantic, i.e. only if integration is independent of what is processed, can such a temporal platform be used for such a purpose. Thus, the complementarity of identity and dynamics which are essential for perception and thinking is made possible by the 3-second window.

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