Presented at ACM CHI Workshop W14: *Changing Perspectives of Time in HCI* April 27th 2013

# Subjectively Experienced Time in HCI

**Lassi A. Liikkanen**
Helsinki Institute for Information
Technology HIIT
Aalto University, Finland
lassi.liikkanen@hiit.fi

**Paula Goméz Gómez**
Department of Computer Science
University of Helsinki



## Abstract
System response times have been traditionally used in software engineering as an indicator of quality in temporal matters. This theoretical position paper argues for new measures of time in interaction design and research. By introducing the concept of subjectively experienced time (SXT), we convey the idea that subjective feeling of time passing is more important than any objective measure of duration. We review psychological literature on human time perception and synthesize a model of time perception to describe on-line subjective time estimation. As the main contribution, our model includes appraisal as a mediating mechanism from 'raw cognitive' perception to emotional experiences of use. In conclusion, we discuss the need for future work, especially regarding retrospective time estimates and the association of time factors to user experience.

## Keywords
Time, interaction design, user experience

## ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

## General Terms
Human factors

## Introduction

Time factors are inherently present in technology use. There is no interaction without a reaction. Delays, interruptions, and waiting for services influence the use behavior. For instance, being put on hold on a call increases the likelihood of hanging up the call [21]. Slow responses may cause the user to abort the task as Conn [3, p. 186] writes: "a wrong conclusion about a delay… can have serious consequences." The assumed connection of negative emotion and waiting makes subjectively experienced time important. For example, several authors have discussed how affective and cognitive factors together influence system use behavior and technology acceptance [8, 25, 35, 39].

Our main premise is that experiences are evaluated positively when the passing of time is not noticed. Previous research shows that this is a shared belief, at least in Western cultures [33]. Making people believe the time flew (advanced quickly) affects their enjoyment of the task – even if this belief is inaccurate (*ibid.*). Therefore, we introduce a new concept of *subjectively experienced time (SXT)* and argue that it should take precedence over response times commonly considered in the human-computer interaction (HCI) literature.

HCI research has typically treated time through system response and user response times [7]. The lack of design perspectives has been noted, but neither fulfilled [19] nor recently updated [see 3]. Similarly the concepts we use to talk about time in HCI are outdated. The HCI community has neither acknowledged the psychological understanding of human time experiences nor articulated the design implications of this knowledge. This paper argues that by considering *subjectively experienced time* as a user requirement in design, one can improve interaction design and build better user experiences (UXs).

In this paper, we briefly review theories and findings from the psychological literature that concerns time perception. We then move on to introduce a novel model of human time perception for online duration judgments. With this proposal, we hope to inspire discussion among the audience about the appropriate concepts to discuss time in HCI and the understanding of its psychological underpinnings.

## Theories of Time Perception

Humans are capable of maintaining a daily rhythm and keeping the track of time, thanks to innate rhythms and external cues. There are several, complementary and sometimes contradictory theories of time perception dealing with different temporal intervals [10, 23]. Here, we build on the scalar estimation theory [SET; 13, see 14], a quite well known variant, that explains absolute and relative time judgments in some animals, including humans.

SET proposes that time judgments are based on the functioning of an internal pacemaker, which produces pulses to be detected by an accumulator. The number of pulses collected by the accumulator counts towards the perception of time, enabling time estimation. This mechanism relies on short-term memory, and it is complemented by an assessment and decision making process. In this process, the new time estimate is compared to expectations about how long this activity should take [9, 14] retrieved from long-term memory. This allows duration assessments in both objective (seconds, minutes) and subjective terms (short, long).

This model is supported by neuroscientific evidence from humans [e.g. 29]. SET has proven successful for modeling several empirical data sets, though these have mostly involved intervals of few seconds.

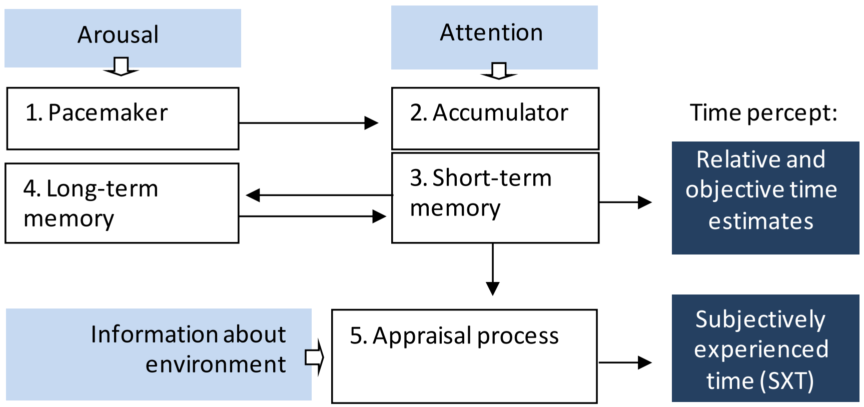


Figure 1. A variation of the scalar estimation theory presented by Gibbon (1977) and reproduced by Droit-Valet & Gil (2009) for human time perception. Thin arrows represent information flow. Block arrows indicate modulation.

Here we propose a variation of the SET model, which is illustrated in Figure1. The variant integrates recently introduced parts of time psychology with the original SET model and, attempts to help understand human time perception more thoroughly. The main changes in the model concern the inclusion of *attention, affect* and *appraisal*.

Our emotional state, or foremost *arousal*, influences the rhythm of the pacemaker. Increasing arousal speeds up the pacemaker, causing more pulses to be sent within the same time. Arousal is modulated by emotional stimuli [27], stimulation of dopanimergic receptors [9], and changes in body temperature [41]. Arousal can also be temporarily modulated by diurnal variation [30]. This can be one reason why people are less tolerant for delays during the lunch time than later on in the day [34] and more accident-prone in the morning and afternoon "lows" [20] because of the decreased arousal is matched with increased drowsiness and fatigue during those times. However, the modulating influence of affect on time perception in laboratory experiments seems short-lived, although highly arousing events can be overestimated also in retrospective estimation [36]. For instance, overestimation bias disappears after two seconds [1].

The effects of attention on time perception are distinct from the affective ones. The role of *attention* in our model can be clarified by thinking of time estimation as an independent task [5]. The allocation of attention to the timing task determines the awareness of time passing, i.e. time feels longer when you pay attention to it. Time estimation does not require our full attention, but the more occupied we are elsewhere, the less the pulses accumulate and the less we notice time passing [14], as if a connection between pacemaker and accumulator was switched off [40]. An empirical study supports this: "*introspective estimates of time spent on a task tightly correlate with the period of availability of central processing resources*." [5, p. 1110] In other words, attention modulates perception. Some mental processes are hard to time subjectively because of their high attentional demands. This reflects the changed perception of time when people are highly engaged in their tasks [4, 6].

A related observation is that time estimation is influenced by simultaneous action. A person who performs an action, perceives the intervals between causally linked events, e.g. pressing a button and receiving response, shorter than if they occurred without a connection. This seems important for control tasks [7] in HCI, because this coupling bias is most pronounced at about 250 ms, leveling off around 650 ms. [16]

The view of time perception presented this far is lacking a decision making and actuation part we call *subjective assessment*. However, in SET variations, complex *appraisal* mechanisms are not commonly included, even though their role in real life situations is acknowledged [9, 33]. The psychological appraisal theory of emotion describes how people judge the pleasantness of experiences *after the experience* based on their interpretation of the situation [12]. This theory assumes emotional reactions are an outcome of an evaluation process in which the initial visceral feelings are interpreted against other sources of information. Appraisal is necessary in understanding how we *feel* about the outcome of time estimation. From here on we try to connect time estimation and appraisal theory of emotion [e.g. 31] to time perception.

In the modified SET model presented in Figure 1, appraisal is depicted in step 5 and it receives input from time estimation, learned expectations, and information filtered from the environment. As an outcome, this process generates a feeling of *subjectively experienced time* (SXT), a meta-cognitive judgment [33]. The traditional division of control and conversational tasks in HCI [7], reminds us how the subjective assessment of the situation determines acceptable response times [7, 34]. The interpretation of the situated, contextual experience rather than the SRT alone determines the emotional reaction and the same situation may evoke a different SXT depending on the appraisal. In the context of computer systems, the number of factors influencing the appraisal process is considerable and everything depends on how well the user understands the system, the extent and accuracy of their mental models about the system [2].

The variant of SET is useful for understanding concurrent (prospective) time estimation relevant for momentary UX [32]. But it is of limited utility for retrospective assessment ("*how long did it feel like*") associated with episodic UX. This also means that the timing information is rarely encoded because it is not in the locus of attention during task execution. According to Droit-Volet & Gil (2009, p. 1946), "*the retrospective temporal judgment is then re-constructed on the basis of the non-temporal information retrieved from memory.*" This connects time perception to emotions and makes it vulnerable for interventions which claim, for instance, that duration was shorter than experienced [33]. But what is more important is that only experiences which evoke strong emotional responses become distinctive and important ones.

*Experimental manipulations of time perception*

Several types of manipulations can influence our time perception. For the illustrative purposes, we introduce few effects and their possible explanation in the following.

Informational interventions while waiting can influence SXT. Harrison and associates have studied the progress bar commonly used in software to provide estimates about the remaining time until task completion [17, 18]. Their study participants tolerated negative system behavior, slowing down and pausing, best during the beginning of the wait. Non-linear progress bars that start off slowly but accelerate towards the end resulted in a feeling of a rapid conclusion favored by the users

[17]. Authors do not provide profound explanations for why this happens. Given that the waiting time in their experiments was on average 5.5 seconds, these findings might be best explained using Vierordt's law [22], although this phenomenon might also illustrate a peak-end bias common to all experiences [11].

In a numbers of experiments by Sackett et al. (2010), it was discovered that people evaluate experiences as more enjoyable and shorter in duration if they are manipulated to believe that time flew while completing the task. The three manipulations included a variable task length, a constant task length with variable alleged length, and an accelerating or decelerating timers shown. All manipulations influenced the appraisals of the experience (*time duration* and *task enjoyability*), showing the importance of the appraisal process in influencing subjective assessment. However, if the participant had an absolute reference from a clock, the manipulation effect diminished. Similarly, if the participants were given an alternative explanation for the passing of time ("earplugs make time fly/drag"), the impact of the manipulation was also vanished. [33]

Pastime or a secondary task can distract user's attention away from waiting. The use of music or computer games as pastime has been recently investigated. The intuitive notion of computer games making time fly received rapport in a recent study in which gaming adolescents in comparison to a group reading a book significantly underestimated the duration of the task [38]. This is likely an attentional effect, because arousal would evoke opposite results.

Music seems to influence both affective and attentional components of time perception. In a study conducted by Guéguen and Jacob [15], participants were holding on a telephone line. They waited while either listening to instrumental music deemed enjoyable for waiting, or in silence. The waiting time was less overestimated by the participants who listened to music than those who did not. This confirms that waiting time is overestimated, even though long intervals would generally be underestimated based on Vierordt's law [22]. Background music has been found to reduce perceived waiting time also in another telephone study [26]. Slow tempo music resulted in restaurant patrons occupying their table longer and spending more money than patrons exposed to the same music played at a faster tempo [24]. One could argue that multitasking with music, as the people studied by Ophir and Nass [28] sometimes did, are taking advantage of these influences for emotion or attention regulation.

## Discussion and Future Directions

This paper proposed that the subjective experience of time should become a requirement for system design and not assumed to be solved by electrical or software engineering alone. We showed how changes, or reductions, in SXT, especially related to waiting, can indirectly contribute toward better UX and, consequently, to an increased satisfaction or preference toward the system. Our literature review illustrated how time perception could be manipulated, for instance how information can influence appraisal of the experience and modulate emotions. We also presented a psychological theory of subjectively experienced time to explicate why working of the manipulations.

We have presented theories of human time perception and related empirical findings. Building on existing psychological theories, we stressed the importance of appraisal that is based upon all available information. Appraisal is crucial for the assessment and creation of experiences with regards to pleasantness and time. We are currently extending this work to present explicit design implications, questions for further empirical research in basic and applied settings, and relating it to the HCI discussions on user experience research and design.

We see that in future, the concept of SXT should be tested and developed. The most important step is to explore the solutions to the challenge '*how to measure SXT*'. This far we have discussed only subjective response times (measured from too fast to too slow) and not provided any specifics about recording the emotional responses relevant to SXT. For the latter, different types of emotion instruments utilized by psychologists, e.g. the self-assessment manikin [37], could be used together with probes focusing on the cognitive appraisal of the situation. There is also the issue of prospective vs. retrospective evaluation, i.e. when should SXT be assessed. Considering the existence of the peak-end bias [11], *retrospective evaluation s*eems more important and should bring forth especially *negative* episodic UXs. This suggests that the relationship between SXT and different types of UX seems an issue worth exploring and we believe this work can be beneficial to the study of both HCI and UX.

## Acknowledgements

This work was supported research projects *Lutus* (http://hiit.fi/LUTUS) by Technology Industries of Finland Centennial Foundation and *Theseus II* by Finnish Technology Agency Tekes.

## References

[1] Angrilli, A., Cherubini, P., Pavese, A. and Manfredini, S. The influence of affective factors on time perception. Attention, Perception, & Psychophysics, 59, 6 (1997), 972-982.

[2] Bouch, A., Kuchinsky, A. and Bhatti, N. Quality is in the eye of the beholder: meeting users' requirements for Internet quality of service. In Proceedings of the the SIGCHI conference on Human factors in computing systems (CHI'00) (Amsterdam, The Netherlands, 2000). ACM Press.

[3] Conn, A. P. Time affordances. The time factor in diagnostic usability heuristics. In Proceedings of the Proceedings of the SIGCHI conference on Human factors in computing systems (CHI'95) (Denver, Colorado, United States, 1995). ACM Press.

[4] Conti, R. Time flies: Investigating the connection between intrinsic motivation and the experience of time. Journal of Personality, 69, 1 (2001), 1-26.

[5] Corallo, G., Sackur, J., Dehaene, S. and Sigman, M. Limits on Introspection: Distorted Subjective Time During the Dual-Task Bottleneck. Psychol. Sci., 19, 11 (November 1, 2008 2008), 1110-1117.

[6] Csikzentmihalyi, M. Creativity: Flow and the Psychology of Discovery and Invention. HarperPerennial, New York, 1996.

[7] Dabrowski, J. and Munson, E. V. 40 years of searching for the best computer system response time. Interacting with Computers, 23, 5 (2011), 555-564.

[8] Dillon, A. and Morris, M. G. User acceptance of new information technology: theories and models. in Annual Review of Information Science and Technology, , 31 (1996), 3-32.

[9] Droit-Volet, S. and Gil, S. The time-emotion paradox. Philosophical Transactions of the Royal

Society B: Biological Sciences, 364, 1525 (July 12, 2009 2009), 1943-1953.

[10] Eagleman, D. M., Tse, P. U., Buonomano, D., Janssen, P., Nobre, A. C. and Holcombe, A. O. Time and the Brain: How Subjective Time Relates to Neural Time. The Journal of Neuroscience, 25, 45 (November 9, 2005 2005), 10369-10371.

[11] Fredrickson, B. L. Extracting meaning from past affective experiences: The importance of peaks, ends, and specific emotions. Cognition & Emotion, 14, 4 (2011/10/07 2000), 577-606.

[12] Frijda, N. H., Kuipers, P. and Ter Schure, E. Relations among emotion, appraisal, and emotional action readiness. J. Pers. Soc. Psychol., 57, 2 (1989), 212.

[13] Gibbon, J. Scalar expectancy theory and Weber's law in animal timing. Psychol. Rev., 84, 3 (1977), 279-325.

[14] Grondin, S. Timing and time perception: A review of recent behavioral and neuroscience findings and theoretical directions. Attention, Perception, & Psychophysics, 72, 3 (2010), 561-582.

[15] Guéguen, N. and Jacob, C. The influence of music on temporal perceptions in an on-hold waiting situation. Psychology of Music, 30, 2 (2002), 210.

[16] Haggard, P., Clark, S. and Kalogeras, J. Voluntary action and conscious awareness. Nature Neuroscience, 5, 4 (2002), 382-385.

[17] Harrison, C., Amento, B., Kuznetsov, S. and Bell, R. Rethinking the progress bar. In Proceedings of the Proceedings of the 20th annual ACM symposium on User interface software and technology (Newport, Rhode Island, USA, 2007). ACM.

[18] Harrison, C., Dey, A. K. and Hudson, S. E. Evaluation of progressive image loading schemes. In Proceedings of the Proceedings of the 28th international conference on Human factors in computing systems (CHI'10) (Atlanta, GA, 2010). ACM.

[19] Hildebrandt, M., Dix, A. and Meyer, H. A. Time design. In Proceedings of the CHI '04 extended abstracts on Human factors in computing systems (Vienna, Austria, 2004). ACM.

[20] Horne, J. A. and Reyner, L. A. Sleep related vehicle accidents. British Medical Journal, 310, 6979 (1995-03-04 00:00:00 1995), 565-567.

[21] Kortum, P., Bias, R. G., Knott, B. A. and Bushey, R. G. The effect of Choice and announcement duration on the estimation of Telephone Hold Time. International Journal of Technology and Human Interaction, 4, 4 (2008), 29-53.

[22] Lejeune, H. and Wearden, J. H. Vierordt's The Experimental Study of the Time Sense (1868) and its legacy. European Journal of Cognitive Psychology, 21, 6 (2011/08/09 2009), 941-960.

[23] Meck, W. H. Neuropsychology of timing and time perception. Brain and Cognition, 58, 1 (2005), 1-8.

[24] Milliman, R. E. The Influence of Background Music on the Behavior of Restaurant Patrons. J. Consum. Res., 13, 2 (1986), 286-289.

[25] Nielsen, J. Usability Engineering. Morgan Kaufmann, San Francisco, 1993.

[26] North, A. C., Hargreaves, D. J. and McKendrick, J. Music and on hold waiting time. Br. J. Psychol., 90, 1 (1999), 161-164.

[27] Noulhiane, M., Mella, N., Samson, S., Ragot, R. and Pouthas, V. How emotional auditory stimuli modulate time perception. Emotion, 7, 4 (2007), 697-704.

[28] Ophir, E., Nass, C. and Wagner, A. D. Cognitive control in media multitaskers. Proceedings of the National Academy of Sciences, 106, 37 (2009), 15583.

[29] Rao, S. M., Mayer, A. R. and Harrington, D. L. The evolution of brain activation during temporal processing. Nature Neuroscience, 4, 3 (2001), 317-323.

[30] Refinetti, R. and Menaker, M. The circadian rhythm of body temperature. Physiology & Behavior, 51, 3 (1992), 613-637.

[31] Roseman, I. J., Spindel, M. S. and Jose, P. E. Appraisals of emotion-eliciting events: Testing a theory of discrete emotions. J. Pers. Soc. Psychol., 59, 5 (1990), 899.

[32] Roto, V., Law, E., Vermeeren, A. and Hoonout, J. User Experience White Paper. Bringing clarity to the concept of user experience. City, 2011.

[33] Sackett, A. M., Nelson, L. D., Meyvis, T., Converse, B. A. and Sackett, A. L. You're Having Fun When Time Flies: The Hedonic Consequences of Subjective Time Progression. Psychol. Sci., 21, 1 (November 1, 2009 2010), 111-117.

[34] Seow, S. C. Designing and Engineering Time: The Psychology of Time Perception in Software. Addison-Wesley Professional, Boston, MA, 2008.

[35] Shackel, B. Usability-context, framework, definition, design and evaluation. in Human factors for informatics usability (1991), 21-37.

[36] Stetson, C., Fiesta, M. P. and Eagleman, D. M. Does Time Really Slow Down during a Frightening Event? PLoS ONE, 2, 12 (2007), e1295.

[37] Thüüring, M. and Mahlke, S. Usability, aesthetics and emotions in human-technology interaction. International Journal of Psychology, 42, 4 (2011/09/20 2007), 253-264.

[38] Tobin, S. and Grondin, S. Video games and the perception of very long durations by adolescents. Computers in Human Behavior, 25, 2 (2009), 554-559.

[39] Venkatesh, V. and Davis, F. D. A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. Manage. Sci., 46, 2 (2000), 186-204.

[40] Wearden, J. H. "Beyond the fields we know...": exploring and developing scalar timing theory. Behavioural Processes, 45, 1-3 (1999), 3-21.

[41] Wearden, J. H. and Penton-Voak, I. S. Feeling the heat: Body temperature and the rate of subjective time, revisited. The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology, 48B, 2 (1995), 129-141.

[42]