Time and Timing in Human-Computer Interaction

Martin Riemer
martin.riemer@tu-berlin.de
Technical University Berlin
Berlin, Germany

Johanna Bogon
johanna.bogon@ur.de
University of Regensburg
Regensburg, Germany

Nele Russwinkel
nele.russwinkel@uni-luebeck.de
University of Lübeck
Lübeck, Germany

Niels Henze
niels.henze@ur.de
University of Regensburg
Regensburg, Germany

Eva Wiese
eva.wiese@tu-berlin.de
Technical University Berlin
Berlin, Germany

David Halbhuber
david.halbhuber@ur.de
University of Regensburg
Regensburg, Germany

Roland Thomaschke
thomaschke@psychologie.uni-freiburg.de
University of Freiburg
Freiburg, Germany

ABSTRACT

Time perception is an integral aspect of human experience and has numerous implications for the communication between humans and computers. When interacting with computers, user experience is often compromised by non-optimal latency and temporal misperception. In this workshop, we gather scientists from diverse research fields (including Human-Computer Interaction, Psychology, Computer Sciences, and Design) to discuss the possibilities of altering the temporal experience of users of interactive systems and to reflect on the potential benefits and risks of such a systematic manipulation. This workshop aims to foster a shared understanding of imminent research questions at the intersection of time perception and HCI research and to identify strategies for tackling them in collaborative projects.

KEYWORDS

Time, Timing, Duration, Human-Computer Interaction, Human-Robot Interaction, Virtual Reality

1 BACKGROUND

While the influence of time and timing has largely been neglected in traditional Human-Computer Interaction (HCI) research, it now gets increasingly acknowledged that temporal factors like delays, durations and time-based expectations crucially shape our cognitive and emotional interaction with computers. Consequently, research on temporal aspects is increasing in various fields of HCI. This boost of HCI-related timing research produces striking new findings of high applicability. For example, the design and structure of interaction environments determine how we deal with temporal system delays of different duration and, thus, dictate whether delays facilitate or impair our performance, whether we experience delays as aversive and captive, or as acceptable or even desirable [2–4, 9]. Likewise, our perception and feeling of time depends on interface design choices: The interaction environment influences how long we estimate the interaction duration, whether we impatiently focus on the flow of time or, on the contrary, become entirely unaware of time passing by [1, 8]. However, most HCI-related time and timing research findings come from specialized application areas, such as robotics, gaming, and virtual reality (VR). Although these specialized lines of research are flourishing, they are primarily disconnected, with little convergent theorizing or even mutual awareness between each other. This workshop will bring together leading figures and early career researchers currently involved in cutting-edge research on different areas of time and timing in HCI. We aim to develop a common terminology and taxonomy spanning various application areas, from Human-Robot Interaction (HRI) over gaming to VR. By discussing potential theoretical frameworks connecting previously disparate lines of timing research, we aim to estimate the generalizability of novel findings across different applications, paving the way for evidence-based design guidelines for optimal temporal experience design.

Time perception is a fundamental aspect of every experience. Whether we are waiting for our computer to complete a process, experiencing the effects of network delay in an online multiplayer video game, or interact with robots in a social setting – time is ubiquitous. Manipulating how time is perceived can be a powerful source of either frustration or satisfaction. Notably, the valence of different temporal characteristics changes for different situations. For example, the unpredictability of time delays in programming can be frustrating. At the same time, it can be vital to increase the perceived authenticity of social interactions with AI technologies [16, 29]. To disentangle the complexity of time and its effects, our discussions during the workshop will center on three temporal aspects relevant for HCI: Temporal delays, durations, and expectations.

Veröffentlicht durch die Gesellschaft für Informatik e.V. in P. Fröhlich und Vanessa Cobus (Hrsg.): Mensch und Computer 2023 – Workshopband, 03.-06. September 2023, Rapperswil

https://doi.org/10.18420/muc2023-mci-ws05-106

1.1 Temporal Delays, Durations, and Expectations

In HCI, the temporal delay between input and output (latency) alters the users' experience. While in some scenarios, such as video telephony, a low latency enhances user experience, the principle of "less latency is better" may be too simplified in others and can even be disadvantageous. Human cognitive processes often endure longer than a computer's calculations. Therefore, too swift outputs can be as frustrating as prolonged ones. Both too swift and prolonged outputs may interfere with the quality of user experience according to the principle of computational rationality [16].

Another crucial aspect influencing user experience when using interactive systems is how we perceive temporal durations. The perception of time devoted to an application, for example, when booking a doctor's appointment or playing a video game, depends on various factors, such as the application's purpose or level of immersion. Therefore, manipulating those factors can systematically alter the perception of durations, which is particularly relevant for highly immersive interaction techniques such as VR. Previous work, for example, demonstrated that the spatial layout of a (virtual or real) environment affects perceived durations [1, 19].

Furthermore, repeated interactions with technical systems allow us to develop temporal expectations, such as how long it takes for a computer to boot up. These expectations help us detect abnormalities and prepare for timely responses. Our comprehension of the world is based on expectations, even for things we cannot directly observe [21]. In social interactions, we have expectations regarding the intentions and timing of feedback from other humans. If the expected feedback is not received within a specific time window, the meaning changes, and we may assume hesitation instead of confirmation. The same is applicable when operating interactive systems.

All three constructs – temporal delays, durations, and expectations – are crucial to understanding the influence of time and timing on the user's experience. Systematic and well-coordinated studies on this issue will provide a solid basis for defining optimal conditions for the temporal design of interactive systems.

2 TIME AND TIMING IN HUMAN-COMPUTER INTERACTION

Time and timing play a crucial role in all facets of HCI. From HRI to video games and VR, the timing of actions and feedback can significantly impact the user experience and performance. In the following, we briefly explore the complexities of time and timing in HCI, and how they differ across various domains.

2.1 Time and Timing in Human-Robot Interaction

HRI research faces several critical challenges in terms of timing. First, robots typically operate relatively slowly to avoid causing harm. However, human interaction partners expect interactions to be fluent and not to slow down task completion. Second, humans expect robots to behave similarly to human partners because that is the only relatable mental interaction model [16]. If the robot's timing diverges strongly from the expected timing, humans may interpret this negatively. Third, the human partner requires feedback that supports complex interactions. If the robot fails to give feedback and makes mistakes, it can cause intense frustration in the human partner [29]. The artificial partner's lack of transparency and unexpected behavior is especially problematic and must be addressed for a successful interaction. Therefore, it is crucial to understand the appropriate timing of actions and feedback for such interactions. Finally, in human interactions, we usually have specific predictions about our partner's subsequent actions to support or engage in joint action, where both partners' actions are well-coordinated [28]. This requires a mental model of the task and a partner that is temporally adaptive to the situation.

2.2 Time and Timing in Video Games

In video games temporal components fundamentally shape player-game interaction. Previous research, for example, illustrates that latency negatively affects gaming experience and player performance [2, 4, 5, 9]. Although technical compensation methods exist [3, 23], reducing players' subjective temporal asynchronicity is a promising approach to circumvent the negative effects of temporal delays. Other work demonstrates that attentional resources allocated to the game are a key factor in the players' temporal perception [15, 22]. However, it still needs to be understood how game design and human time perception interact. Time perception in video games is crucial on a macro level, for example to show how playing video games leads to a systematic underestimation of time [15, 17], but it is also crucial on a micro level, for example, when predicting in-game events. Players need to temporally anticipate in-game events to excel in particular video games [27]. However, research in this area, investigating how temporal expectations interact with video game mechanics, is still underrepresented. Further interdisciplinary research is needed to investigate how game design can modulate the gaming experience and player performance through temporal components and predictive game elements [24].

2.3 Time and Timing in VR

VR technologies are rapidly pervading almost all areas of HCI, enabled by their immersive potential and an unprecedented degree of realism. From the early days of ergonomics VR research, a central issue has been determining how subjective experience differs between real and VR-simulated situations. In recent years a growing number of publications highlighted that the experience of time systematically differs between real-world and VR scenarios [14]. However, the findings from different VR applications are inconsistent [10, 11, 26]. For example, timing accuracy is affected by spatial features of the simulation [18]. Yet, it is also reduced when users are confronted with more complex tasks [8], when their movements are rendered at a slower pace [20], or when immersion increases [12]. In addition to quantitative duration estimates, VR environments also affect the qualitative experience of time. The felt speed of time-flow increases when the user is represented by an avatar [25], and the time spent in a waiting room is experienced as more boring in VR than in a real waiting room [6]. Based on these findings, researchers are developing VR tools to systematically manipulate human temporal experience along different dimension [7], for example, by distorting users' movement speed [13].

Time	Schedule Item
09:00 - 09:15	Welcome
09:15 - 09:45	Introduction round
09:45 - 10:15	Opening keynote talk by the organizers
10:15 - 10:45	Coffee break
10:45 - 12:15	Individual presentations of the participants
12:15 - 13:15	Lunch break
13:15 - 14:15	Discussions and brainstorming in topic-related groups
14:15 - 14:45	Summarize group discussions in topic-related groups
14:45 - 15:15	Coffee break
15:15 - 15:45	Group presentations
15:45 - 16:15	Making plans
16:15 - 17:00	Closing

Table 1: Tentative workshop schedule.

3 GOALS OF THE WORKSHOP AND WORKSHOP STRUCTURE

Our workshop aims to integrate basic research findings on time and timing into actionable and practical HCI research. Ultimately, we aim to establish interdisciplinary research that (1) paves the way for temporally human-aware robotic systems, (2) sheds light on how video games and human time perception interconnect, and (3) provides joint design guidelines for time-related issues, for example, in VR.

To achieve this, we will gather researchers from different disciplines who are investigating temporal aspects of action, perception, situations, or processes in HCI contexts (e.g., researchers from the fields of HCI, Robotics, or Human Factors) or who are conducting relevant basic research of these aspects relevant to HCI (e.g., researchers from the fields of Psychology or Cognitive Sciences). The workshop intends to identify intersections and differences regarding the interests and competencies of the multidisciplinary participants and to identify challenges of interdisciplinary collaboration in investigating time and timing in HCI. The long-term goal is to build a thematically and structurally connected community of interdisciplinary researchers who will collaborate on future research projects and develop a cross-disciplinary taxonomy for investigating temporal factors in HCI.

This is a discussion-based workshop. The workshop is planned as a one-day event and will be held as an in-person workshop. The tentative schedule of the workshop is illustrated in Table 1. After welcoming the participants, we start the workshop with the introduction round (each participant introduces themselves with a 1 min pitch). Afterward, the organizers will give an introductory keynote about the workshop organization and the three topics. After a short break, participants will then give a 3-4 minute presentation on their papers. After an extended lunch break, they will join their predefined discussion groups. These discussion groups will include discussion and brainstorming around the topic area. A workshop organizer will moderate each discussion group. Then, the results of the discussion groups will be summarized by the groups in 1-3 slides and (after a short break) presented to all participants. Finally, we will discuss short- and long-term collaborative plans.

ORGANIZERS

The organizing team combines expertise and interests from HCI, psychology, robotics, and games research.

Martin Riemer is postdoc researcher at the Institute of Psychology and Ergonomics at the Technical University Berlin. His research is focused on time perception and spatial cognition, especially on the temporal and spatial aspects of VR applications and HCI.

Johanna Bogon is postdoc researcher in the media informatics group at the University of Regensburg. She has a background in cognitive psychology and is interested in the bilateral transfer of basic psychological research and HCI research. In particular, she focuses on the integration of temporal features in action and perception and their impact in HCI contexts.

Nele Rußwinkel is professor for Human-Aware AI at the University of Lübeck. She is a cognitive scientist and expert for cognitive modeling in dynamic human-machine systems. Her work focuses on interaction scenarios in complex settings such as pilots, highly autonomous driving, and human robot collaboration.

Niels Henze is professor of Media Informatics at the University of Regensburg. His research interests are mixed reality and mobile human-computer interaction. Particularly, he is interested in the design of mixed reality systems. His recent work focuses on understanding how embodied avatars affect perception and physiological responses in virtual reality.

Eva Wiese is professor of Cognitive Psychology and Cognitive Ergonomics at the Technical University of Berlin. Her research focus is on Human Factors and Social Robotics.

David Halbhuber is a Ph.D. student in Media Informatics at the University of Regensburg. His research focuses on the effects of latency in video games and on novel approaches to latency compensation in video games.

Roland Thomaschke is professor of Psychology at the University of Freiburg and head of the research group *Time, Interaction, Self-determination*. His research focuses on human time perception, temporal expectancy, and temporal experience.

REFERENCES

[1] Vanessa Aeschbach, Sonja Ehret, Joana Post, Miriam Ruess, and Roland Thomaschke. 2020. The Effect of Waiting Environment and Perceived Atmosphere on Temporal Experience. (2020). https://doi.org/10.5709/acp-0351-3

[2] Wouter Durnez, Aleksandra Zheleva, Mark Claypool, Klaas Bombeke, Mathias Maes, Jan Van Looy, and Lieven De Marez. 2021. Spaz! The effects of local latency on player actions in an desktop-based exergame. *IEEE Transactions on Games* (2021). https://doi.org/10.1109/TG.2021.3128714

[3] David Halbhuber, Niels Henze, and Valentin Schwind. 2021. Increasing Player Performance and Game Experience in High Latency Systems. *Proceedings of the ACM on Human-Computer Interaction* 5, CHI PLAY (2021), 1–20. https://doi.org/10.1145/3474710

[4] David Halbhuber, Annika Köhler, Markus Schmidbauer, Jannik Wiese, and Niels Henze. 2022. The Effects of Auditory Latency on Experienced First-Person Shooter Players. In *Proceedings of Mensch und Computer 2022*. 286–296. https://doi.org/10.1145/3543758.3543760

[5] David Halbhuber, Maximilian Schlenczek, Johanna Bogon, and Niels Henze. 2022. Better be quiet about it! The Effects of Phantom Latency on Experienced First-Person Shooter Players. In *Proceedings of the 21st International Conference on Mobile and Ubiquitous Multimedia*. 172–181. https://doi.org/10.1145/3568444.3568448

[6] Federico Alvarez Igarzábal, Helena Hruby, Joanna Witowska, Shiva Khoshnoud, and Marc Wittmann. 2021. What Happens While Waiting in Virtual Reality? A Comparison Between a Virtual and a Real Waiting Situation Concerning Boredom, Self-Regulation, and the Experience of Time. (2021). https://doi.org/10.1037/tmb0000038

[7] Maximilian Landeck, Fabian Unruh, Jean-Luc Lugrin, and Marc Erich Latoschik. 2020. Metachron: A framework for time perception research in VR. In *26th ACM Symposium on Virtual Reality Software and Technology*. 1–3. https://doi.org/10.1145/3385956.3422111

[8] Jiaxin Li and Ji-Eun Kim. 2021. The Effect of Task Complexity on Time Estimation in the Virtual Reality Environment: An EEG Study. *Applied Sciences* 11, 20 (2021), 9779. https://doi.org/2076-3417/11/20/9779

[9] Shengmei Liu, Mark Claypool, Atsuo Kuwahara, James Scovell, and Jamie. 2021 Sherman. 2021. Lower is Better? The Effects of Local Latencies on Competitive First-Person Shooter Game Players. In *CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, 285–297. https://doi.org/10.1145/3411764.3445245

[10] Jean-Luc Lugrin, Fabian Unruh, Maximilian Landeck, yoan Lamour, Marc Erich Latoschik, Kai Vogeley, and Marc Wittmann. 2019. Experiencing Waiting Time in Virtual Reality. In *25th ACM Symposium on Virtual Reality Software and Technology* (Parramatta, NSW, Australia) *(VRST '19)*. Association for Computing Machinery, New York, NY, USA, Article 69, 2 pages. https://doi.org/10.1145/3359996.3364807

[11] Steven C Mallam, Jørgen Ernstsen, and Salman Nazir. 2020. Accuracy of Time Duration Estimations in Virtual Reality. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 64. SAGE Publications Sage CA: Los Angeles, CA, 2079–2083. https://doi.org/10.1177/1071181320641503

[12] Donna Lynn Monbourquette. 2019. *Ahead of its Time: An exploration of virtual environment effects on time estimation.* Ph.D. Dissertation. Carleton University.

[13] Paul Morat, Aaron Schwerdtfeger, and Frank Heidmann. 2021. In Case You Don't Know What To Play: Framework for a VR Application that manipulates Time Perception through Spatial Distortion. In *Mensch und Computer 2021*. 609–613. https://doi.org/10.1145/3473856.3474035

[14] Grayson Mullen and Nicolas Davidenko. 2021. Time compression in virtual reality. *Timing & Time Perception* 9, 4 (2021), 377–392. https://doi.org/10.1163/22134468-bja10034

[15] Filip M Nuyens, Daria J Kuss, Olatz Lopez-Fernandez, and Mark D Griffiths. 2020. The potential interaction between time perception and gaming: A narrative review. *International Journal of Mental Health and Addiction* 18, 5 (2020), 1226–1246. https://doi.org/10.1007/s11469-019-00121-1

[16] Antti Oulasvirta, Jussi PP Jokinen, and Andrew Howes. 2022. Computational Rationality as a Theory of Interaction. In *CHI Conference on Human Factors in Computing Systems*. 1–14. https://doi.org/10.1145/3491102.3517739

[17] Cecilia Paasche, Sébastien Weibel, Marc Wittmann, and Laurence Lalanne. 2019. Time perception and impulsivity: A proposed relationship in addictive disorders. *Neuroscience & Biobehavioral Reviews* 106 (2019), 182–201. https://doi.org/10.1016/j.neubiorev.2018.12.006

[18] Tyler Read, Christopher A Sanchez, and Raffaele De Amicis. 2021. Engagement and time perception in virtual reality. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 65. SAGE Publications Sage CA: Los Angeles, CA, 913–918. https://doi.org/10.1177/1071181321651337

[19] Martin Riemer, Jonathan P Shine, and Thomas Wolbers. 2018. On the (a)symmetry between the perception of time and space in large-scale environments. *Hippocampus* 28, 8 (2018), 539–548. https://doi.org/10.1002/hipo.22954

[20] Michael Rietzler, Florian Geiselhart, and Enrico Rukzio. 2017. The matrix has you: realizing slow motion in full-body virtual reality. In *Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology*. 1–10. https://doi.org/10.1145/3139131.3139145

[21] Nele Russwinkel, Leon Urbas, and Manfred Thüring. 2011. Predicting temporal errors in complex task environments: A computational and experimental approach. *Cognitive Systems Research* 12, 3-4 (2011), 336–354. https://doi.org/10.1016/j.cogsys.2010.09.003

[22] Hans Rutrecht, Marc Wittmann, Shiva Khoshnoud, and Federico Alvarez Igarzábal. 2021. Time speeds up during flow states: A study in virtual reality with the video game thumper. *Timing & Time Perception* 9, 4 (2021), 353–376. https://doi.org/10.1163/22134468-bja10033

[23] Valentin Schwind, David Halbhuber, Jakob Fehle, Jonathan Sasse, Andreas Pfaffelhuber, Christoph Tögel, Julian Dietz, and Niels Henze. 2020. The Effects of Full-Body Avatar Movement Predictions in Virtual Reality Using Neural Networks. In *26th ACM Symposium on Virtual Reality Software and Technology* (Virtual Event, Canada) *(VRST '20)*. Association for Computing Machinery, New York, NY, USA, Article 28, 11 pages. https://doi.org/10.1145/3385956.3418941

[24] Roland Thomaschke and Carola Haering. 2014. Predictivity of system delays shortens human response time. *International Journal of Human-Computer Studies* 72, 3 (2014), 358–365. https://doi.org/10.1016/j.ijhcs.2013.12.004

[25] Fabian Unruh, Maximilian Landeck, Sebastian Oberdörfer, Jean-Luc Lugrin, and Marc Erich Latoschik. 2021. The Influence of Avatar Embodiment on Time Perception-Towards VR for Time-Based Therapy. *Frontiers in Virtual Reality* (2021), 71. https://doi.org/10.3389/frvir.2021.658509

[26] Ineke JM van der Ham, Fayette Klaassen, Kevin van Schie, and Anne Cuperus. 2019. Elapsed time estimates in virtual reality and the physical world: The role of arousal and emotional valence. *Computers in Human Behavior* 94 (2019), 77–81. https://doi.org/10.1016/j.chb.2019.01.005

[27] Robbert van der Mijn and Hedderik van Rijn. 2021. Attention Does Not Affect the Speed of Subjective Time, but Whether Temporal Information Guides Performance: A Large-Scale Study of Intrinsically Motivated Timers in a Real-Time Strategy Game. *Cognitive Science* 45, 3 (2021), e12939. https://doi.org/10.1111/cogs.12939

[28] Robrecht P.R.D. van der Wel, Cristina Becchio, Arianna Curioni, and Thomas Wolf. [n.d.]. Understanding joint action: Current theoretical and empirical approaches. 215 ([n. d.]), 103285. https://doi.org/10.1016/j.actpsy.2021.103285

[29] Alexandra Weidemann and Nele Rußwinkel. 2021. The Role of Frustration in Human–Robot Interaction–What Is Needed for a Successful Collaboration? *Frontiers in Psychology* (2021), 707. https://doi.org/10.3389/fpsyg.2021.640186