

Time and Temporality in HCI Research

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'Time' and 'temporality' are increasingly addressed in human-computer interaction (HCI) research. From issues related to mapping and visualizing data along timelines via explorations of temporality as a design material to studies of lag and the rhythms of work, time is a recurring perspective in HCI research. In fact, time has been a recurring aspect in HCI research for the past 30 years. Based on this continuous and growing interest in HCI research, we find it to be a good time to explore if 'time' can be used as a way to structure and organize HCI research. In this paper, we make one such attempt based on a literature study in which we have focused on how time and temporality has been addressed in HCI research during the past 30 years. In our overview of the field, we explore how time and temporality has played out in HCI along the two dimensions of *what* and *how* it has been studied. Based on these two dimensions, we created a 4×4 matrix that allowed us to filter the material and categorize HCI research in relation to time and temporality. As a result of our explorations, we have identified a turn to *temporality as a design material* in HCI, an interest in *methods for temporality studies* in HCI and in *temporality as a theoretical lens*. We end with a discussion of some implications of our findings around the notions of (i) waves of time and temporality studies in HCI research, (ii) the potential use of the 4×4 matrix and (iii) the consequences of a more fundamental shift from things to events.

RESEARCH HIGHLIGHTS

- This paper foregrounds the continuous and growing interest in 'time' and 'temporality' in HCI research
- We present an overview of how 'time' and 'temporality' has played out in HCI over the past 30 years
- Based on this overview, we propose a 4×4 matrix that allowed us to filter the material and categorize HCI research in relation to time and temporality.
- We contribute to existing work in HCI with a focus temporality as a design material, and how temporality might work as a methodological approach and theoretical lens.

Keywords: interactivity; interaction; temporality; time; HCI

Handling Editor: Helen Petrie

Received 4 May 2021; Revised 1 July 2021; Accepted 28 July 2021

1. INTRODUCTION

As the field of human-computer interaction (HCI) develops over time, the need for overviews of our field increases. Over the past 15 years, HCI research has seen a number of literature overviews focused on different aspects of the field, but there is still a lack of overviews of how time and temporality has been dealt with in HCI research, although there are a number of related overviews. For instance, Bødker provided the field with an overview of the evolution of the three 'waves' of HCI (Bødker, 2006, Bødker, 2015). Based on Bødker, other overviews have sparked and fueled discussions about the

next steps forward for the field, including discussions on what a fourth wave of HCI could be (see e.g. Frauenberger, 2019; Ashby *et al.*, 2019), and how to understand recurring challenges in our field (see e.g. Rydenfält and Persson, 2020). Over the years, we can notice that these overviews have covered a number of central topics in HCI, ranging from the overviews of HCI and usability (Wiberg, 2005), to paradigms of game research in HCI (Carter *et al.*, 2014), HCI and culture (Clemmensen and Roese, 2010), to recent overviews of research on e.g. subtle interaction (Pohl *et al.*, 2019), embodied interaction (Lee-Cultura *et al.*, 2020) and the history of human–automation interaction (Janssen *et al.*,

2019). In short, we notice an increasing interest in literature reviews that seeks to add to our understanding of how HCI as a field has developed over time. At that same time, and in relation to this, we notice that there are still no overviews published on how the field of HCI has approached the notion of *time*, theoretically, conceptually and pragmatically, and how this has changed *over time*.

Motivated by this growing interest in overviews of our field, we will here focus on how time and temporality—as a central component in human–computer interaction—has been addressed in HCI research over the past 30 years. We explore this topic along the two axes of *what* has been studied when it comes to time and temporality, and *how* it has been studied.

As an overarching contribution, we suggest that our work adds to the establishment of time and temporality-oriented studies in HCI as a particular strand of research focused on understanding how time shapes and affects human–computer interactions.

It should be said here, and in line with similar overviews conducted (see e.g. Clemmensen and Roese, 2010 and Lee-Cultura *et al.*, 2020), that the main purpose of our study is not to create a comprehensive map of how ‘time’ has been approached in HCI research, since we do not think that it is either possible or necessary for our purpose. Instead, our research is an attempt to explore if ‘time’ can be used as a way to structure and organize HCI research, that is, to establish an overview of how time and temporality has played out in HCI over time. We engaged with this research after several encounters with colleagues and students where the notion of ‘time’ emerged as a core concept in their research. At the same time, it seemed difficult to position their research in relation to other ‘time’ related research. We asked ourselves if and how it might be possible to categorize ‘time’ related HCI research and also if that could help us to see any developments or changes over time regarding how ‘time’ has been addressed in HCI research. Accordingly, this research is primarily explorative and aiming to open up new questions in relation to the notion of ‘time’ in HCI research.

2. BACKGROUND—THE NOTIONS OF ‘TIME’ AND ‘TEMPORALITY’

The notion of ‘time’ represents one of the oldest and most complex philosophical subjects. As described by West-Pavlov (2013), ‘time’ is a term that at first glance may seem to be utterly common sense, but upon closer scrutiny, it ‘transpires to be one of the oldest and most complex subjects of philosophical reflection, artistic representation and aesthetic discourse as it virtually underpins all aspects of everyday life’. Even though time has not always been dealt with as a philosophical concept in HCI research, it is present in many diverse ways and often without being explicitly addressed, from issues related to mapping and visualizing data along time lines via explorations of temporality as a design material to studies of lag and the

rhythms of work. Time is today a recurring perspective and variable and a matter of its own studies.

Time (and temporality) has been a topic or dimension in many studies of information technology design and use (see e.g. Loup *et al.*, 2017; Wild *et al.*, 2004), in computer supported cooperative work (CSCW) (e.g. Jackson *et al.*, 2011; Lindley, 2015) and in HCI (see e.g. Harrison and Cecchinato, 2015; Mead and Pacione, 1996; Thomas *et al.*, 2013; Vaara *et al.*, 2009), but we believe that something has changed during the past 5 years. One assumption behind our research is that ‘time’ has shifted from serving as a secondary or implicit dimension or aspect to more clearly denote a particular strand of research in HCI where ‘time’ is a core fundamental and even primary concept.

Time and temporality constitute a key dimension of all human–computer interaction due to being almost unavoidable in all types of computing and to all forms of interaction and is therefore central in almost any study of HCI, which also makes it almost impossible to completely isolate and capture how it has been approached. But as we mention, a more intentional and explicit focus of temporality has grown in contemporary studies in HCI and is, in many cases, part of the research design (see e.g. Lundgren and Hultberg, 2009; Odom *et al.*, 2018a,b), in explorations of ‘slow interaction’ (Hallnäs and Redström, 2001; Odom *et al.*, 2012b; Saakes *et al.*, 2010) and in attempts to theorize interaction as a temporal activity (e.g. Benford and Giannachi 2008; Huang and Stolterman, 2011, 2014; Odom *et al.*, 2018a,b; Siegel and Beck, 2014; Wiberg, 2018). In relation to this steady and expanding interest, we suggest that it is both possible and important to closer examine how temporality in HCI research is expanding and *what* and *how* it has been studied.

As part of our approach, we have conducted a literature study on how ‘time’ and ‘temporality’ has been addressed in a selected part of HCI research over the past 30 years. Based on our findings, we created a 4×4 matrix that allowed us to organize not only areas that have been studied (*what*) but also the approaches taken in these studies (*how*). As a result of our findings, we argue that there are some emerging areas that call for further empirical and conceptual explorations, and we suggest that the increasing focus on temporality denotes a shift in HCI research *from things to events*. We end by discussing what implications this shift may have for how we study, theorize and construct methods for explorations of ‘interaction’ and ‘interaction design’ in HCI research.

2.1. A timely movement from *things* to *events*

Traditional design fields love things (including e.g. industrial design, product design, etc.). Designing leads to the creation of things, artifacts, objects and products, even though today we have seen a shift from concrete things to abstract things, such as services and systems. In the field of HCI research, which deals with computing or computational things, the notion of

things has always been central. The field studies and develops computationally infused ‘things’. We are living in a world that is flooded with computational things, with interactive artifacts. The language we use to describe our everyday environments seem to be full of ‘thing’ words, such as device, object, artifact, gadget, products and computers. And, of course, we have the notion of IoT—the Internet of Things.

It has been a successful strategy for the field of HCI research to engage with the perspective of ‘things’. It has led to new ways of thinking about interactivity as technology has made new forms of interaction possible. Developing new, interactive ‘things’ has been a productive way of exploring new design spaces and testing new forms of interaction and interactivity. The ‘things’ themselves have constituted new knowledge and insights, as well as these new forms of interaction. Major conferences have, in parallel with paper sessions, showcased sessions where ‘things’ are displayed, and it’s possible to explore and experience them.

In parallel with this successful ‘thing’ approach, HCI research has also explored interaction as something that has to do with time, that is, with events, processes and activities rather than things. The temporal aspect of interaction has always attracted interest in the field. Any system that supports turn-taking between man and machine relies on a temporal model (no matter if it is a dialogue interface, where the system waits for the user to reply, or if it is a game where the challenge is to respond fast). Temporality has increasingly become a design dimension in interaction design and not, as in earlier times, a consequence of the system’s capacity and response time, or studies that has foregrounded how things change, evolve, or are adapted over time, or how tasks change when artifacts are changed (see e.g. Carroll’s task-artifact model, Carroll, 2003). While HCI has shifted from its early concentration on the things and tools of office workers to a much broader canvas (including e.g. the internet of things), we now see a growing interest in understanding aspects of temporality in HCI research.

Given what we see as an increasing interest in time and temporality in HCI research, we find it surprising that there is, so far, no survey or review of the area. We have not found any research that in any systematic way examines what has been done to the present, and no studies on this shift from things to events in HCI. Of course, there is some research that illustrates both practical and reflective perspectives on time and temporality in HCI, and we have been inspired by some HCI researchers who have developed different aspects of temporality and interaction. For instance, the work by Hallnäs and Redström (2001) on slow interaction and Odom *et al.*’s (2018a,b) work on time and temporality as a design material illustrate this reflective stance on time and temporality in HCI. In addition to these strands of HCI research, we notice Benford and Giannachi’s (2008) work on the notion of ‘trajectories’, Chung-Ching and Stolterman’s (2011) descriptions of interaction as a series of events, and Lowgren and Stolterman’s (2007) work on ‘interaction qualities’ and ‘interaction gestalt’.

In short, there seems to be a growing body of research aimed at conceptualizing time and temporality in HCI, and there is an interest in exploring interaction through a temporality lens.

2.2. Some notes on the concepts of ‘time’ and ‘temporality’

Before we start our analysis, we should say a few additional words about the two core concepts in our study: *time* and *temporality*. There is a whole research field, outside of HCI, dedicated to the study of time and temporality (West-Pavlov, 2013), and it ranges from mechanical models of time (i.e. ‘clock-time’) to phenomenological models focused on ‘lived time’, that is, the inner experiential time. In this article, we rely on the work by West-Pavlov’s broad understanding of time and temporality to make sure that we do not apply too narrow of a filter as we go through the published research on time and temporality in HCI. In relying on the work by West-Pavlov, we define ‘temporality’ as the state of existing within or having some relationship with time.

When we turn to HCI, the two concepts, time and temporality, are ubiquitous and appear in all sorts of contexts with all kinds of meanings in the HCI literature. Commonly, when the notion of temporality is mentioned in HCI research, it does not mean more than that certain aspects of time are seen as important and that special attention is paid to it, but it does not necessarily mean that time is treated conceptually or theoretically in any advanced way. Most of the literature that we have analysed fall into this category.

There is a whole vocabulary of time and temporality concepts in the HCI literature, including *longitudinal*, *ongoing*, *long-lasting*, etc. There are also a set of notions used in HCI research that speaks to the character of temporality, such as if an interaction is fast, slow, interrupted or recurring. Notions such as *pace*, *frequency*, *rhythm*, *lag*, *speed*, etc. are used for this purpose. In our study, we acknowledge the existence of all of these related concepts while trying to be sensitive to how they are used in relation to the notions of time and temporality.

3. METHODOLOGY

Approaching a research area as vast as HCI in some comprehensive way is not possible at least not without extraordinary resources. This means that trying to fully capture how *time* and *temporality* has been addressed in HCI research publications is a daunting task. So, to be able to do anything reasonable within limited time and resources, we had to make a lot of decisions concerning what we should count as HCI research, what the data sources should be, what time period we should focus on, how closely we should examine each publication, etc.

We ended up choosing an approach similar to what others have done when analysing and surveying research in HCI. We have been inspired by similar reviews of our field including e.g. the work by DiSalvo *et al.* on mapping out the landscape

of ‘sustainable HCI’ research (DiSalvo *et al.*, 2010), HCI and culture (Clemmensen and Roes, 2010), overview of HCI and culture and the most recently published overview of HCI and embodied interaction by Lee-Cultura *et al.* (2020). In detail, we have been inspired by the aim formulated by DiSalvo *et al.* to ‘map out the approaches being taken and the intellectual commitments that underlie the area, to allow for community discussion about where the field should go’ (DiSalvo *et al.*, 2010, p. 1975). This aim overlaps with our ambition to map out HCI research in relation to time and temporality.

In our study, we have worked back and forth between an ongoing, open-minded analysis of a selected collection of published work on time and temporality in HCI research, and the analytical frameworks that have already been published that explicitly sets out to address issues of temporality in HCI. We chose this approach since we did not want to prematurely adapt to any given understanding of temporality without a broad exposé of existing literature. This iterative process has resulted in a model that can be used to categorize HCI research in the way it deals with time and temporality.

It should be noted here that the scope of our study is, in certain ways, very different from the study by DiSalvo *et al.* (2010). The sustainability review was done when there were only few research publications in HCI on the topic. The researchers of the study could actually develop a corpus of all relevant publications in the field at the time. We were facing a fundamentally different situation since it is possible to argue that almost every publication in HCI research deals in some ways with time and temporality. Given that time and temporality is such a fundamental cornerstone of virtually any form of human-computer interaction, our approach and process had to be different in terms of corpus and process. In the following sections, we expand on this in relation to the corpus and our methodological approach to this issue.

3.1. The corpus

Our analysis began with a creation of a corpus of papers that we saw related to time or temporality. We started this process without having a clear definition of what ‘related to’ would mean. Our intention was to be generous at the start and to be inclusive rather than exclusive, allowing the growing corpus to guide us. With this strategy, we managed to conduct an extensive literature review of a corpus of published work. As already mentioned, we did not cover the whole field of HCI research in all its richness. For instance, we did not include monographs or edited books. Instead, we decided to limit our search and only collect papers from the ACM Digital Library. We picked this library since it covers publications coming out of the ACM SIGCHI community, with all its journals and conferences. This library also makes it possible to conduct comprehensive searches of the materials based on the same search functions and words. For our study, we saw the ACM library as representative when it comes to HCI research that

emerges from the SIGCHI community. Of course, this library does not cover all relevant HCI research, but as active members of the SIGCHI community we found this limitation to be reasonable and pragmatic.

3.2. The process

In framing our literature review, we searched the ACM Guide to Computing Literature on the terms ‘time’ and ‘temporality’ in relation to ‘HCI’ and ‘interaction design’ research. We also used synonyms for ‘time’ and ‘temporality’ as to ensure that we covered publications with an explicit focus on temporal aspects of HCI. Based on this framing, the queries to the ACM digital library included the following terms: *time*, *temporality*, *temporal*, *tempo*, *rhythm*, *pace* and *lag*. Through this scoping, we ended up with a total of 529 papers. It is important to note that we did not have any ambition to be comprehensive or complete, neither do we see the corpus as a correct representation of HCI research. However, we found that our corpus provided us with a rich set of materials, highly diverse, that challenged us in our ambition to find organizational categories, and therefore served well as a corpus for our purpose.

Two rounds of review of these papers were performed to ensure relevancy. Inclusion criteria included full and complete studies with a focus or emphasis on time or temporality in the area of HCI (e.g. papers on the pace of interaction, how users experience lag, or the pace of interaction, and papers on variations of interaction temporality, for instance papers on ‘slow interaction’). Exclusion criteria included papers that only mentioned time, temporality or related words, but did not have it as a focus. We realized quickly that these criteria are not precise or easy to apply, but they helped us to not only select a corpus but also as tools in our search for how time and temporality has been approached. Each decision of inclusion or exclusion gave us some more information of what role time and temporality has played in the field.

For the analysis of this corpus, we applied a meta-synthesis approach (Jensen and Allen, 1996) to survey the collected literature. The meta-synthesis approach was selected since it supports the creation of ‘higher levels of abstraction’ (Jensen and Allen, 1996), which is important in order to create an overview of a whole field of research. This method and approach is also similar to other attempts at analysing research in HCI (see e.g. DiSalvo *et al.*, 2010). In addition to this, we selected the meta-synthesis approach since it provides a framework for synthesizing qualitative findings, which enabled us to group the collected papers as a set of categories related to *what* has been studied and *how* it has been studied in relation to time and temporality. In doing so, we followed the stages of the interpretive synthesis as proposed by Jensen and Allen (1996), in terms of locating relevant papers, grouping these into categories and synthesizing these categories internally by revisiting the collected papers while creating the overview.

Our intention with the analysis was to develop a model that could be used to describe HCI research in relation to time and temporality. We imagined that it would be possible to create categories and concepts that would be suitable to describe the way time was dealt with. We also had the goal that the model should not be too complex with too many categories. We did not try to be comprehensive by being detailed. Instead, we tried to be comprehensive on an abstract level, that is, by making sure that we would have broad enough categories that they would cover most of the papers in our corpus. We anticipated the model not to be truly depictive in any detailed, analytic way aimed at the determination of individual papers but to function as a tool for discussion and reflection of the field as such.

3.3. Emerging categories

Our aim was to formulate categories that would help us to understand how HCI researchers approach time and temporality. During the process, several potential categories emerged, and we worked back and forth between the corpus and potential categories. Our analysis finally led to the identification of *two types of categories*. We distinguish between aspects that have to do with *what* the research is studying and the aspect of *how* the research is done. With this in place, we tried to establish a set of categories for each type. We tried to keep the number of categories low. This means that we ended up with two types of categories and four subcategories within each type.

A few words on the nature of emergent categories and patterns. We are not making any claim that we have found the correct categories or the only ones that make sense or can provide interesting insights. Our categories are a consequence of our selection of literature and of how we approached the literature, and of our own preconceived notions about the state and nature of HCI research. However, we do claim that our categories, however simple and somewhat intuitive, provide a tentative descriptive overview of HCI research in relation to time and temporality. And since this has not been done before, we believe it can serve as a valuable contribution, and a starting point for further investigations.

We will first present and discuss the categories that describe what the research is focused on, and then we will discuss the way, the how, research is done.

3.4. HCI research and *what* is studied

As mentioned above, our analysis of *what* HCI research has studied in relation to time has led to the development of a model with four categories. These four categories denote what the research is focused on, i.e. its object of study. After working with these categories, we realized that it was possible to combine them into a simple model that resonates surprisingly well with the common understanding of the field of HCI. The four categories are as follows:

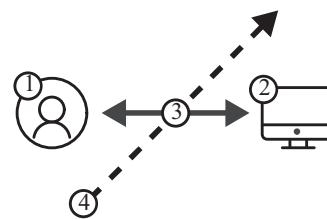


FIGURE 1. Basic object of study—the HCIOt model.

- 1) **HUMANS**—On the pace and rhythms of work and life
- 2) **COMPUTERS**—Fundamental principles for computing and visualizations
- 3) **INTERACTION**—Temporal explorations of interaction
- 4) **over TIME**—Phases in time and historical perspectives on time and HCI

It became clear that these four categories could be related to each other in the same way as HCI is typically represented, that is, with a figure that includes three elements: a human, a ‘computer’ and the interaction between the two. Our fourth category seemed to denote the first three elements as a system, as a whole, and how that whole and its relationships move and change over time (Fig. 1). That is the HCI over Time (HCIOt) model.

We will now first present each category of this HCIOt model and describe how we define them, with references to papers that exemplify each category of *what* is studied.

3.4.1. (1) HUMANS—on the pace and rhythms of work and life

Time is what structures our lives as humans, and how technology influences that structure and our lives has drawn a lot of interest from HCI researchers. Concepts such as pace, frequency, rhythm, interruption, etc. have been essential dimensions for organizing our life and worlds around the use and adoption of computers. In our corpus, we found a large number of papers that addressed this type of time-related issues. With computers, we can work ‘anytime, anywhere’ (Kleinrock, 1996), but as a research community, we have explored technology support for both synchronous and asynchronous ways of working (e.g. Ludden and Meekhof, 2016) and communicating (Ellis *et al.*, 1991). Today, we even have support for reminding us to take breaks and to limit our screen time (Wiberg and Wiberg, 2019). Lots of research has been done on how to work efficiently (fast) with computers (see e.g. Frøkjær *et al.*, 2000), but there have also been studies on ‘immersion’ and the lost sense of time (Kujala *et al.*, 2013), e.g. when playing computer games (see e.g. Nordin *et al.*, 2013). There are also studies on collaborative work across time zones, on interruptions (and how long it takes before getting back to the task at hand), on lag in computer games, etc. In short, all these studies suggest that *humans* are an essential part of *what* is studied from a temporal perspective in HCI.

In the same way as the *human* part is understood in the concept of *HCI*, we use the notion *human* in a broad sense, capturing all forms of human aspects, such as individuals, groups, communities, societies, etc.

To exemplify the human aspect, we can look to the notion of rhythm. We notice, for instance, the work by Wild *et al.* (2004) on the temporal aspects of work for HCI and the more recent work by Jackson *et al.* (2011) on ‘collaborative rhythms’. For sure, this strand of research covers many papers, and we also noticed how it has more recently been extended to other sites beyond the workplace, e.g. the work by Light and Petrelli (2014) on ‘the rhythm of Christmas’ or examinations of temporal integration of interactive technology in dance (Latulipe *et al.*, 2011). In going through our corpus, we noticed that a majority of the work published on temporal aspects of HCI had a CSCW framing. Some examples of that include that work on making time by Lindley (2015), studies on the slip of time (Harrison and Cecchinato, 2015) and studies on latency in the development of groupware systems (Savery and Graham, 2011). In addition to that, we also found some studies in HCI on lag, delays and waiting time, e.g. the work by Asthana *et al.* (2015).

Overall, this category captures a major part of traditional HCI research. This research is focused on how computational technology influences how people live and work together and as individuals. Traditionally, it seems to have been focused on supporting people to be more efficient and able to do more with computer support, but over the past 15 years, we have seen research emerging that explores other aspects of time and temporality and engages with supporting people to reflect, rest, exercise and stay healthy.

3.4.2. (2) COMPUTERS—fundamental principles for computing and visualizations

In addition to a central concern for studying *humans*, there has always been an interest in understanding *computers* from a temporal perspective in HCI. We use the concept of computer to signify the technological side of the interaction between people and technology. It is a broad and inclusive notion used in a generous way.

In fact, it is almost impossible to imagine a computer without considering it from a temporal perspective. Time and temporality is fundamental to how a computer works—from reading instructions in a particular order (over time), to clock cycles, loops, timers and counters in computer programs, to batch processing (processing data at a later time) and time-sharing. Semaphores (with its basic stop/wait design) and the chronological writing to the hard drives during the 1980s and 1990s are additional examples. Time has been essential throughout the history of the design of computing machinery. *Order* and *frequency* are fundamental notions to how a computer operates—from how it steps through a computer program to how it reads data—it is all about the temporal order of things. Further, the notion of frequency deals with recurring elements (over time).

But it is not only for the internal operations of a computer that time and temporality is central. Across the history of computing, we have also relied on temporality in the presentation of the *output* from the computer. We have designed the computers to display information along timelines (information visualization), and we can order files in relation to when a file was created (or edited). We can also sort information in chronological order (e.g. in the file system). In short, it seems like computing would not be possible if we removed the temporal dimension from its design.

From our literature, it is obvious that a substantial amount of research has been directed towards *computers* as a core aspect of *what* is explored through a temporal lens. In HCI research, time has been explored as an interface design dimension as to enable the computer to represent data (e.g. Mead and Pacione, 1996). This idea has been further explored by, for instance, Darlow and Goldin (2011) in efforts made for making graphical interfaces consistent with causal temporal order. Indeed, there is a large set of papers published on the use of computers for making visualizations including everything from timelines to temporal visualizations that are dynamic and interactive. For instance, Dubinko *et al.* (2006) explored the visualization of tags or time, Benford and Giannachi (2008) focused on temporal trajectories in shared interactive narratives and Zhao *et al.* (2012) proposed solutions for interactive faceted browsing of timeline data.

Overall, this category captures some of the fundamentals of computing. Processing, clock cycles, loops, counters, etc. are essential processes for any computer. In addition, this category also captures HCI’s history of research on interactive visualizations and how computational power has enabled dynamic visual presentations of information.

3.4.3. (3) INTERACTION—temporal explorations of interaction

Over the past decade, research related to the temporality of interaction has become more common. Not only have computers increased processing speed, but we increasingly also have faster processing of huge amounts of data, faster computer networks and faster interaction models. Whether we consider stock trading or online gaming, we notice these fast models of interaction that demand short reaction times from the stock broker or the online gamer.

In relation to this trend, HCI research has not only been concerned with *humans* and *computers* as two separated entities but also has been focused on understanding and exploring models for the *interaction* between these two. For instance, research has focused on how to use fast interaction models to make computer games more challenging or to explore models for slow interaction, or to develop models that describe interactions leading to desired user experiences.

It seems that despite Moore’s law (with faster and faster computer processing), the pace of everyday interaction has been about the same over the years. For instance, we type in

word processors in about the same pace as we did 30 years ago, so it is hard to say that the pace of interaction has changed. Further, we design computer games where more advanced levels are designed for faster movements or shorter response times (time is accordingly a design variable here to make the game harder for each level). Dialogue-based systems are also designed around this ‘normal pace’ interaction model. The user typed in a command, the system replied and then the user typed a new command. Most recent developments have started to challenge this basic turn-taking model. AI can work in the background at high speed, track the users’ actions and make predictions that can further speed the interaction, or, in some cases, make the interaction obsolete (Janlert and Stolterman, 2017).

Over the past decade, the ‘normal pace’ model of interaction has been challenged, e.g. the slow interaction design movement (see e.g. Hallnäs and Redström, 2001; Odom *et al.*, 2012b; Saakes *et al.*, 2010). There are other related explorations here as well, for instance, work on how information items can start to fade away as time passes (Odom *et al.*, 2014).

In reviewing the existing strand of research on time and temporality in HCI, we notice some articles explicitly focused on *interaction* and how temporality plays an important role in the *experience of the interaction over time*. For instance, Christensen (2014) explored the sculpting of a temporal experience for the listener. In this strand of research, we also find a number of papers on how a change in the temporality can change the experience of the interaction. This includes published papers on slow technology (Hallnäs and Redström, 2001) and work that extends this perspective to new domains including e.g. King and Forlizzi’s work on slow messaging to support intimate communication for couples living at a distance (King and Forlizzi, 2007), slow design for meaningful interactions (Grosse-Hering *et al.*, 2013) and work on slow displays (Saakes *et al.*, 2010). We also find critical reflections on time and temporality in relation to slow technologies (see e.g. Cheng *et al.*, 2011; Odom *et al.*, 2012b) and research projects that have explored design frictions for mindful interactions (Cox *et al.*, 2016).

We also identified work on how to increase awareness of the temporality of the interaction, including the work by Kusunoki and Sarcevic (2015) on design for temporal awareness in time-critical teamwork. Finally, we saw several examples of not only slowing down interaction but also exploring different temporal themes in interactive artifacts (e.g. Lundgren, 2013).

Overall, this category captures how time and temporality research in HCI has not only been focused on how *work with computers* has been arranged around temporal models (e.g. synchronous vs. asynchronous work, work hours vs. leisure hours, time sharing, etc.), humans’ capacity to process information (e.g. studies of cognition, memory, reaction time, eye-hand coordination, etc.), or *how the computer works* (including e.g. clock cycles, processing speed, lag, etc.) but also how time and temporality are fundamental aspects of any interaction model.

Whether if we design a word processor, a system for the stock market, a tool for design, a game or an app for reflection, a model that accounts for the *pace of interaction* is essential. In fact, as interaction unfolds over time, any interaction model needs to reflect this. In our literature review, we noticed a growing strand of research in HCI explicitly devoted to studies on this temporality of interaction.

3.4.4. (4) Over TIME—phases in time and historical perspectives on time and HCI

During our process, we also found examples of research that engages with a time or temporal perspective on the field of HCI research itself. Maybe the most well-known example might be Bødker’s (2006) description of the ‘*three waves of HCI*’. In this paper, she describes how the third wave of HCI implied that the use context and application types were broadened and intermixed relative to the focus of the second wave, where the main focus was on work. Indeed, this illustrates how the particular phase in time we are at also governs our research focus. Accordingly, this is a fundamental aspect if we want to understand matters of time and temporality in HCI, i.e. it is not only something that enables computing or something we organize ourselves and our interactions around. Far beyond that, the historical moment we are in defines the scope and focus of the research to a large extent. In short, history matters. From this viewpoint, it is then again obvious why Bødker revisited this 10 years later (Bødker, 2015) to examine how HCI had changed over the previous decade. Indeed, this interest in understanding HCI through a temporal and historical lens has been shared by other researchers in HCI. For instance, Kapteinlin *et al.* (2003) noticed a shift to post-cognitivist HCI and second wave theories, and Duarte and Baranauskas (2016) revisited the three waves in HCI and proposed an orientation toward philosophy of science in HCI. With a similar argument in terms of the need for new grounds, DiSalvo (2014) highlighted the need for design history in HCI.

HCI has also been through additional sets of changes. For instance, Robles and Wiberg (2010) acknowledged a material turn in HCI, and Xu (2019) most recently noticed how we are now moving towards human-centered approaches to AI as we enter the third wave of developments in Artificial Intelligence research. Indeed, these changes in our field happen over time and form the research agenda for each phase. In addition to these broader studies of changes in our field, we also found studies that explicitly examine how the landscape of time and temporality studies have developed over the years (see, for instance, Odom *et al.*, 2012b, and their examination of how the area of slow technologies has developed over the past 10 years).

Overall, this category captures how HCI has indeed been through several phases over time, and that there is a strand of literature that acknowledges these shifts. While for instance Bødker’s (2006) description of the ‘*three waves of HCI*’ suggests this, our literature study adds to our understanding of such waves and shifts in the field by acknowledging a whole set

TABLE 1. The HCiot ‘Human–Computer Interaction—over Time’ matrix.

WHAT /HOW	Human	Computer	Interaction	over Time
1) Empirical				
2) Methodological				
3) Theoretical				
4) Design				

of studies aimed at understanding the phases HCI has been through over time. We suggest that these phases and changes over time are necessary to include when mapping out the landscape of how time and temporality has come to shape not only our studies in HCI but also the fundamental scope we have taken as we have moved forward.

3.5. HCI research and *how* time and temporality is studied

Within each category of HCI research that we discuss above, research has been carried out in many different ways. Working with our corpus, we realized that it is also possible to categorize *how* time and temporality has been *approached*, not only what has been studied.

The question of *how* research is conducted raises the complex question of how to describe different forms of research, different approaches and methodologies. In line with our initial ambition to create an easy to understand model, we decided to aim for simplicity and a limited set of categories. In analysing the collected literature, we ended up with a formulation of four categories of *how* HCI researchers approached time and temporality. We labeled these as follows: (i) empirical approaches, (ii) methodological approaches, (iii) theoretical approaches and (iv) design approaches.

At this time, it felt natural to combine our *what* and *how* categories in the a 4×4 matrix consisting of the two axis of *what is studied* and *how it is studied* (Table 1).

It is important to note that our categories are not clean and distinct. Research is not often the result of only one approach. Some studies might be mostly empirical but do, of course, offer some theoretical implications. Other studies might take a theoretical concept as a point of departure, although the main focus is on design. For analytical purposes though, it is

important to hold these apart to see where our field has been focused and what is still important to explore even more.

To further illustrate our categories, we will present some examples of existing research at the intersections of WHAT and HOW, and we will then use this matrix as a framework to sketch a ‘heatmap’ where we, based on our corpus, identified substantial amounts of research and how it has shifted over time. We have selected individual publications that we believe illustrate the different research approaches taken (*how*) in relation to *what* is studied, i.e. Human–Computer Interaction over Time.

3.5.1. Empirical approaches

Our literature study resulted in a collection of roughly 300 papers that report empirical studies on human–computer interaction in relation to time and temporality. Most of these studies have had an explicit focus on workplaces or homes (e.g. the contexts surrounding humans and studies of synchronous and asynchronous communication, work across time zones, the rhythms of everyday life and daily routines, etc.). We could, of course, also find some more technically oriented research that reported data from studies of how the computer performs while doing different jobs (e.g. solving complex math tasks, compressing video, etc.), but we could not find such studies that were also clearly within the field of HCI.

More closely related to HCI, we found both overviews on the use of computers in daily life and how it develops and changes over time (e.g. Beauvise, 2009), and empirical studies of people multitasking (i.e. doing several things at the same time). We also found studies on how people manage stress and interruptions in their everyday workflow (i.e. studies of attention in relation to performance over time).

In going through this strand of literature, we want to exemplify this very wide set of empirical studies with the following examples. Again, it should be noted here that since there

are at least 300 empirical studies that emphasize time and temporality, we can only cover a fraction of this work in this overview. Still, we hope that these examples illustrate the wide range of studies being conducted here. For instance, Whiting *et al.* (2011) looked at temporal aspects of information and the effect of using long-term temporal profiles of terms in information retrieval applications. On a related note, Irani *et al.* (2010) examined questions of rhythms and plasticity in relation to television temporality at home with a special focus on how digital technologies have enabled new temporalities of media conception, and how practice changes due to new temporal orderings. With a similar focus on changes in practice, Kusmierczyk *et al.* (2015) studied temporality in online food recipe consumption and production with a particular focus on the hidden temporal dynamics in online food communities. Diakopoulos and Naaman (2011) considered the practice of news comments from the perspective of time and temporality in relation to a changing practice.

There has indeed been several empirical studies conducted on group work, collaborations and social interplays from a temporal perspective. O'Connor (2017) looked at the temporality of software development teams, and, in particular, how such work moves beyond 'clock-based' mechanistic understandings of time. Beyond any such simple models, they explored the highly complex, multi-faceted, subtle and socially embedded nature of temporality. In similar terms, Culén *et al.* (2016) examined temporalities and spaces for youth engagement in co-creative activities. Marcu *et al.* (2016) studied times for reflection in computer-supported collaborations, Leshed (2012) looked at ways of slowing down with personal productivity tools and Hawkins *et al.* (2014) examined ways of slowing the pace of media sharing to just mention a few studies that have targeted temporal aspects of computer-supported collaborative work. In addition to these work settings, Yuan *et al.* (2016) and Bogina (2017) studied temporalities in online social interactions, Wu *et al.* (2016) studied multi-scale temporalization of social media popularity and Lee *et al.* (2016) introduced the notion of 'timelessness' in a study of user experience of unplanned smartphone use.

It is not only groups, workplaces and social interaction that has been in focus here, but also individuals. For instance, Umair (2017) looked at individual work behavior in online labor markets with a focus on temporality and job satisfaction. Further, Jang *et al.* (2016) studied the underlying factors of Smart TV UX over time, Buzzo and Merendino (2015) considered how the use and meaning of a digital calendar changed over time and Bauer *et al.* (2013) considered temporal dimensions of privacy settings for the individual. Jatowt *et al.* (2013) reported from a study on focus time. In addition to these studies, we also found some work on the meaning of temporal aspects for the user experience (e.g. Kujala *et al.* 2013).

We also a set of articles that looked at *long-term interactions*, including studies on long-term interactions with slow technology (Odom, 2015), the evolution of information practices over

time (Greyson, 2016) and the emergence of temporal rhythms and patterns in time-critical work (Jagannath *et al.* 2019).

Finally, we found papers that study *rhythms of work* including empirical studies of socio-temporal disorder in distributed teamwork (Norris *et al.*, 2019), temporal dissonance (Jackson *et al.*, 2011), negotiated rhythms of work (Nilsson and Hertzum, 2005) and studies of 'temporal labor' (Raval and Dourish, 2016).

To summarize, the empirical approaches taken to time and temporality in HCI research are typically case studies where work or leisure hours are in focus. Further, there is a focus on how work and other activities are arranged with or around computers, and the results are focused on the temporal dimensions of these activities or changes over time in these settings.

3.5.2. Methodological approaches

The second approach taken to time and temporality in HCI has to do with the development of methodologies capable of capturing temporal aspects of HCI over time. As the field is not only concerned with things but also with events and activities, and how these play out over time, there has been a need to develop methodologies capable of capturing developments and change over time.

In going through this strand of the literature, we found studies aimed at addressing temporal aspects in user modelling (e.g. Bogina, 2017). We also found studies on the use of logic as a way of studying temporality and the lived experience of time (Mazmanian *et al.*, 2015). Several studies focused on the development of methods for applying temporal analytics in practice (e.g. Chen *et al.*, 2016; Yen Lee and Tan, 2017), whereas others have explored methodological approaches for being temporally sensitive in queries (Willis *et al.*, 2016) or doing temporal annotations (Mowery *et al.*, 2008).

Efforts to develop structural methods for conducting temporal analysis in HCI also include some recent work on how to study usability temporalities (Dupuy-Chessa *et al.*, 2016) and methods to study user experience over time (Karapanos *et al.*, 2009).

In addition to these general methodologies developed, we also noticed some published papers devoted to the development of methods to study temporal aspects of human-computer interaction in particular domains or empirical settings, including everything from approaches to examine temporal constraints in human-building interaction (Lundgaard *et al.*, 2019) to approaches for doing temporal network analysis of collaborative learning (Saqr and Nouri, 2020).

Although there is a clear and growing strand of research in this domain, we also noticed how this has only been a focus during the past 5 years (i.e. most of the papers on methodological developments are published between 2015 and 2020).

To summarize, the methodological approaches taken to time and temporality in HCI research denotes a fairly new direction of time and temporality studies in HCI. It is an area where time and temporality are not only considered as a theoretical

	Same Time	Different Times
Same Place	face-to-face interaction	asynchronous interaction
Different Places	synchronous distributed interaction	asynchronous distributed interaction

FIGURE 2. Interaction time/location matrix by [Ellis et al. \(1991\)](#).

perspective, but it is also focused on how data collection and analysis can be conducted with a temporality lens. This growing area of research illustrates that although time and temporality have, to some extent, always been part of HCI, there is still room for new approaches taken to the explicit study of time and temporality in HCI.

3.5.3. Theoretical approaches

A third approach that we were able to identify has to do with research that seeks to theorize and conceptualize *temporal aspects of human-computer interaction*. This strand of research is aimed at developing conceptual frameworks, notions and models of time and temporality in HCI, and the research aimed at developing definitions and vocabularies that allow for a more precise exploration of time and temporality in HCI.

There is some classic research in this area that should be mentioned right away. This includes the classic paper by [Ellis et al. \(1991\)](#) with the time/space matrix where they outlined for basic work modes and what that implied in relation to interaction (Fig. 2).

In addition to this classic matrix, we should also acknowledge the work by [Lowgren and Stolterman \(2007\)](#) on temporal form and the dynamic gestalt of interactive artifacts ([Lim et al., 2007](#)) and interaction ([Stolterman, 2018](#)). This work has established a foundation for more recent work on temporalities in interaction design ([Huang and Stolterman, 2012; Lundgren and Hultberg, 2009; Pschetz, 2015](#)), frameworks for analysing how artifacts change over time ([Huang and Stolterman, 2012; Tsaknaki, 2016](#)), conceptualizations of the pace and rhythm of interaction ([Wiberg, 2018](#)) and explorations of time, tempo and turns in HCI, and how these are related to experiences of time and interaction ([Lundgren, 2013; Thomas et al., 2013](#)).

Related to the pace and rhythm of interaction, there has been a great number of papers published that have developed the conceptual ground for exploring slow computing and slow interaction, including the work by [Hallnäs and Redström \(2001\)](#) on slow computing, [Siegel and Beck \(2014\)](#) on slow change interaction design, [Odom et al. \(2018a,b\)](#) on time, temporality and slowness and their most recent work on slow games and longer-term relations with everyday computational objects ([Odom et al., 2018a,b](#)). Indeed, the very notions of time and temporality in relation to interaction have been explored from a number of perspectives, including both the work by

[Lundgren and Hultberg \(2009\)](#) on time as a design material, and critical work that examines if there is a need to re-think the way we think about time in HCI ([Pschetz, 2015](#)).

There is a growing trend in HCI research to develop conceptual frameworks and theoretical models of time and temporality in HCI. There is some early work, but most of this strand of research has been conducted during the past 10 years. Although the early conceptual work set out to define and conceptually describe temporal aspects of HCI (including the development of notions such as ‘temporal form’ and ‘dynamic gestalt’), or developed categorical frameworks with time as a distinct variable (e.g. the time/space matrix by [Ellis et al., 1991](#)), more recent work has mainly focused on exploring the pace of interaction, i.e. *slow interaction*.

To summarize, we notice how there is both early work that demonstrates theoretical approaches taken to time and temporality in HCI, as well as more recent efforts being made. In going through the literature, we see how the early work (e.g. the time/space matrix by [Ellis et al., 1991](#)) was focused on frameworks for filtering empirical materials, whereas more recent work has been focused on formulating a vocabulary that can address temporal dimensions of interaction (e.g. [Huang and Stolterman, 2011; Pschetz, 2015](#)) or establish a conceptual foundation for studying new directions in HCI and temporality, including the work by [Hallnäs and Redström \(2001\)](#), [Lundgren and Hultberg \(2009\)](#) and [Odom et al. \(2018a,b\)](#).

3.5.4. Design approaches

The fourth approach we could identify represents *design-oriented research approaches to time*. In going through our literature, we can see a growing body of work on time and temporality as a design material or a design variable.

There has been a continuous and expanding interest in exploring slow interaction through design research including the work by [Hallnäs and Redström \(2001\)](#) on slow computing, [Siegel and Beck \(2014\)](#) on slow change interaction design, [Odom et al. \(2018a,b\)](#) on time, temporality and slowness and [Odom et al. \(2019\)](#) on slowness as a frame to design longer-term experiences with personal data. This has indeed been a clear trend, and after almost 20 years of research, it might almost be possible to say that slow computing is a subfield of interaction design. Over the past two decades, we notice how time and temporality has indeed been explored from a multitude of design perspectives, and we notice how this is still a fast-growing area of research in HCI.

Since there is so much design research in this area, we should again say that we cannot mention everything in this overview. Instead, our aim here is to illustrate the main parts that have been covered by our literature study. It is not a complete overview, but it should instead be understood as an attempt to illustrate work on time and temporality in HCI that follows a design approach.

If we now take this as a point of departure, we notice that in addition to the most recent work on slow computing, there

is also some important early work that should be highlighted, including the work by [Kerne \(1997\)](#) on the design of CollageMachine, where they focused on temporality as a design quality for media browsing. This early work has more recently been further explored by [Buzzo \(2017\)](#) in the design of 'The Time Machine' and by Kamila *et al.* (2018) in the design of Tempo-HindiWordNet as a lexical knowledge-base for temporal information processing. In addition to this, there has been some work conducted on temporal hybridity ([Engström *et al.*, 2010](#)) in attempts made to mix live video with instant replay in real time.

We found some papers on temporality in information visualizations and work on temporal dynamics and information retrieval (e.g. [Dumais, 2010](#)). Further, there are a number of design projects on temporality and group work, including [Muñoz-Alcántara *et al.* \(2018\)](#) on the design of a time-oriented collaboration service for design teams and the work by [Combi and Pozzi \(2004\)](#) on the design of a temporal workflow management system.

In addition to these studies, there are also a couple of research projects that has taken some alternative approaches, including the work by [Cardoso and Romão \(2014\)](#) on the timeline as a programming interface and [Buzzo's \(2013\)](#) work that takes the notions of 'input-time' and 'output-time' as a point of departure for exploring how our experience and expression of time and events are connected to each other in a non-linear fashion and what this implies for applications in the areas of lifelogging and quantified self.

In going through the collected papers, we noticed how many interactive systems are built around some form of temporal model, from the chronological sorting of a table to information visualizations that rely on timelines for the presentation of data to groupware systems that rely on temporal models (e.g. [Kusunoki and Sarcevic, 2015](#)). There is also important research in our field that has acknowledged how interactive artifacts change over time ([Huang and Stolterman, 2012](#)) and how such computational things might be designed around different temporal themes ([Lundgren, 2013](#)) or how such artifacts might change the temporality of other things, for instance, the work by [Lindley *et al.* \(2017\)](#) on internet of things-enabled energy temporality.

Existing design research on HCI and temporality is, of course, not only directed toward the exploration and implementation of temporal models in the design of things. Beyond this obvious part of these design efforts taken, we also found interesting design work on temporality and user experience. This includes, for instance, the work by Rosner *et al.* on design with traces and the work by [Obrist *et al.* \(2014\)](#) on the temporality of taste experiences. Here we should also acknowledge the work by [Fuchsberger *et al.* \(2015\)](#) on seven design sensitivities that address time in interaction design and the growing body of work in HCI on shape-changing objects and user interfaces (e.g. the work by [Nørgaard *et al.*, 2013](#)).

Finally, there is some important design research that has acknowledged important dimensions when designing for time across cultures (see [Taylor *et al.*, 2016](#), and [Taylor *et al.*, 2017](#)). There is also a strand of design research in HCI that has explored not only how interactive things change over time but also how things fall apart ([Tsaknaki *et al.*, 2016](#)) and, accordingly, work on design and repair in HCI (see e.g. [Houston *et al.*, 2016](#), and [Rosner and Ames, 2014](#)).

To summarize, we notice that the design approach to time and temporality is a growing field in terms of how most of these papers have been published during the past 5 years. There are of course earlier work, as we have also covered in this section, but in going through the literature, we see how this area is expanding and how it takes on new perspectives on time and temporality, including viewing time as a design material, or focusing on it as a design dimension (e.g. things 'get old', disappear 'over time' or 'falls apart'). Through these explorations, this strand demonstrates how the design approach is a new approach not only to the study of time and temporality in HCI but also to the further exploration of what time and temporality could be in HCI, i.e. how HCI can be re-imagined and further developed.

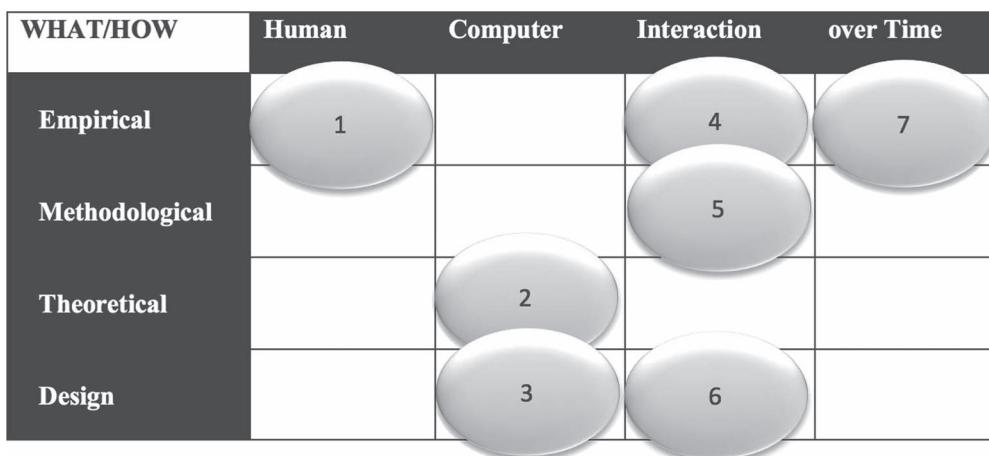
In the next section, we take a step back to examine what these dimensions tell us when we map out the existing research along these dimensions.

4. FINDINGS

As a result from the process of creating and examining our corpus, we found that HCI research has extensively explored some areas of the time and temporality landscape, whereas other areas seem less explored. We will first summarize our findings from the literature review in the 4×4 matrix (introduced above) that visualize *what* and *how* temporality have been addressed in HCI. We will then discuss what this might mean for the HCI research and what implications it may lead to.

4.1. Summary of literature study

Our study has shown that time and temporality has attracted a lot of interest in HCI research over the years. There is a large body of research where time is a significant core aspect or variable. The size of the literature and the diversity of the research related to time make it difficult to grasp and even more difficult to categorize in any 'correct' fashion. This also means that we have not conducted any quantitative analysis of the corpus. Following a lot of considerations, we are convinced that such an attempt would not be successful without more conceptual work in place. Any detailed analysis of the amount of research can be found in each area would first require a more stable understanding of the significant types and categories of time-related research. We do not see our tentative categorization as

TABLE 2. Mapping out the existing work with the HClot 4*4 matrix.

having that stability. Instead, we have chosen another approach where we present our findings at a more abstract level.

We have chosen to summarize the literature based on the categories we have developed above. The table (Table 2) illustrates to what extent, based on our analysis, we find that the corpus reflects HCI research efforts in each area. However, we have been careful not to be too precise with our ‘measures’, which also means that our map should not be read as a detailed representation of the field. However, we believe that our map gives a fairly accurate representation of the corpus and the overall field of HCI research.

In the table, we have marked the cells (intersections) where we have found a substantial amount of published research in our corpus (i.e. >20 published papers). We have intentionally added the markings so they overlap each other and neighboring cells to indicate the complexity of determining what belongs to one cell or another. Given that time and temporality is an aspect of almost any work in HCI, it has not been possible to quantify and add numbers to this matrix. Accordingly, this is not a summary or diagram, but should be read as an overview that provides examples of interesting work, and an overview that points out areas with potential for further research on aspects of time and temporality in HCI.

4.2. Observations on ‘Intersection 1. Humans/empirical studies’

In going through the literature, we noticed—as expected—that there is a large body of published research at the intersection of *humans/empirical studies* (1). In fact, we found ~300 papers published in the major HCI and CSCW outlets that explicitly report on temporal dimensions of human–computer interaction done through mostly empirical approaches. Some examples from the past 10 years are the work by Culén *et al.* 2016; Irani *et al.* 2010; Kusmierczyk *et al.* 2015; O’Connor 2017;

Umair, 2017; and Whiting *et al.* 2011;. This large body of work is not surprising given an understanding of how temporality is an essential aspect that regulates when and how people use, behave and experience their interaction with computers, ranging from studies of the use of computer systems to speed things up to unplanned use (e.g. Lee *et al.*, 2016), temporal aspects of user experience (Kujala *et al.*, 2013), cross-cultural perspectives on time (Taylor *et al.*, 2016), the use of computers during leisure hours (Beauvisage, 2009) and the temporality of online interactions (e.g. Bauer *et al.*, 2013; Yuan *et al.*, 2016).

This strand of research also includes topics such as communication, learning and education; office and information work; working together over space and time (e.g. Jackson *et al.*, 2011; Nilsson and Hertzum, 2005), including studies of multitasking; Fit’s law studies; usability studies; and much more. In going through this large amount of work, we found lots of empirical studies from different application domains with various scales in focus. For instance, we found small-scale studies that investigate the meaning of digital calendars in relation to planning and the use of time (Buzzo and Merendino, 2015) and long-term studies on the evolution of information practices over time (Grayson, 2016).

The overarching aim of this strand of research has been to better understand temporal aspects related to humans by studying them empirically. In going through the publication dates for the articles we collected, we notice that this has been a stable research area over the past three decades (see the work by Lindley, 2015, Lundgren and Hultberg, 2009, Mead and Pacione, 1996, as an illustration of such ongoing efforts), and we noticed that there are still lots of papers published on how the practice of HCI is formed in relation to different aspects of time and temporality, ranging from studies of work practices (e.g. Jagannath *et al.* 2019; Marcu *et al.* 2016; O’Connor, 2017) to the home environment (Irani *et al.* 2010; Jung *et al.*, 2008)

and to social rituals, including the Christmas holidays (Light and Petrelli, 2014).

4.3. Observations on ‘Intersection 2 and 3. Computer/theoretical and design approaches’

There is an extensive strand of literature in HCI (including quite substantial work from computer science) at the intersection of *computer/theoretical work* (2) as well as *computer/design work* (3). This research covers more technical aspects of the fundamentals of computing and processing (including clock-cycles, time-sharing, batch processes, etc.). This is one of the oldest areas that have produced research related to time and interaction. The earliest work we found is by McCann *et al.* (1953) on an evaluation of analog and digital computers. It is fair to say that most of this research is not done with HCI in mind. However, some work, such as Corbató (2003) on *time sharing* as a technique of organizing a computer so that several users can interact with it simultaneously, has a direct consequence and relation to user interaction. The same goes for the work by Desai *et al.* (2000) on itanium processor clock design or the work by Talpes and Marculescu (2003) on adaptive multiple clock processors, even though the research is highly technical and not intuitively HCI oriented. There are only a few examples where such studies intentionally overlap with HCI. Still, this work is fundamental to HCI, so we have included this in our analysis.

In the same intersections (2) and (3), we also find work from the late 1980s and the early 1990s related to the representation of information, including work on dynamic and interactive timelines, information visualizations and techniques for sorting and ordering data chronologically, or along timelines (see the work by Allen, 2005, on a focus-context browser for multiple timelines or the work by Alonso and Shiells, 2013, on timelines as summaries of scheduled events). A large body of this work was conducted in parallel with the development of the GUI—the graphical user interface (see the work by Fox, 1989, on interactive digital video, the work by Dean, 1989, on the use of temporal hierarchies and temporal queries, Eichmann *et al.*, 2017, to efficiently maintain large temporal databases, or the work by Cohen, 1992, on the development of an interactive space–time control for animation and information visualization).

4.4. Observations on ‘Intersection 7. Empirical studies/over time’

In addition, but to a much lesser degree, we noticed how the field has kept a historical perspective on the developments in HCI, and we found several papers that describe developments in the field along different cycles, processes or waves of developments (see Bødker, 2006, 2015; Kaptelinin *et al.*, 2003; Xu, 2019), i.e. studies at the intersection of *empirical studies/over time* (7). It is possible to imagine more research

in this column, especially more theoretical work. Attempts at understanding the historical and potential future development of HCI at a theoretical level would be exciting to the field (and there are of course already good examples of such approaches to the analysis of HCI including e.g. the work by Carroll, 2003). We know from other disciplines that such theoretical depictions help the discipline understand its own identity and responsibility as knowledge producers.

In short, the field has been very active in publishing work on time and temporality in relation to the design, development and testing of computer systems (2) and (3), as well as in relation to how social practice is arranged around these computers (1). Other areas have been less researched, sometimes for practical reasons, and in other cases probably as a result of the tradition in the field. For instance, we found some attempts made to theorize interaction (the intersection of *theoretical approaches/interaction*), but there is still a limited set of studies that explicitly target this area.

4.5. Ongoing shifts

Going through our corpus, we were also able to identify some changes in focus *over time*. In this section, we describe these as ongoing shifts, including (i) a turn to temporality as a design material, (ii) a focus on methods for temporality studies and (iii) temporality as a lens for moving HCI research forward. In the following sections, we describe these shifts in more detail.

4.5.1. A turn to temporality as a design material in HCI

Over the past two decades, HCI has moved from empirical studies of task performance conducted in the 1990s toward design approaches where time and temporality are now increasingly explored as a design material (see Hallnäs and Redström, 2001, and more recently Fuchsberger *et al.*, 2015; Grosse-Hering *et al.*, 2013; Odom *et al.*, 2018a,b; Odom *et al.*, 2019; Rosner *et al.*, 2013). During the past 15 years, this trend in our field is expanding, and we see an expansion of papers published in 2005 and forward with an explicit focus on new designs where time and temporality are explored as a central concept in the interaction design, i.e. at the intersection of *design/interaction* (6). In fact, going through a number of papers published on ‘slow interaction’ since 2001, we notice a continuous exponential growth of published papers in the ACM digital library. Being a necessary component for computing, we notice how this growing strand of design-oriented HCI research approaches time and temporality not as a necessity (e.g. clock-cycles), obstacle (e.g. lag) or consequence of computing (e.g. response time) but as a resource, dimension or interaction design material. In going through the collected literature, we noticed that this shift toward temporality as a design material not only opens a new design space, but it also enables critical analysis of existing designs from the viewpoint of its underly-

ing model of temporality (e.g. the pace, rhythms and frequency of interaction that the design supports).

4.5.2. Increased interest in methods for temporality studies in HCI

Further, we see an increased interest in empirical and methodological approaches to interaction (intersections 4 and 5 in **Table 2**), for instance, the work by Lee and Tan, 2017; Mazzmanian et al., 2015; Willis et al., 2016. This recent work is less concerned with how work is temporally arranged around computers (as in the case of the studies found at intersection (1) and more concerned with studying the flow of the interactions; for instance, the flow of interaction, its pace and rhythm). We suggest that this increasing interest in the development of methods for temporality studies in HCI is crucial as this field of research grows. In early stages, a field can conduct preliminary and explorative studies, but as the field grows, it becomes important to also rely on established methods that make it possible to compare different studies. We also think that this growing interest in the development of methods can fuel the attempts made so far on how to theorize time, temporality and interaction in HCI. For sure, if we want to increase the precision in how we study time and temporality in HCI, we also need a more developed theoretical vocabulary to enable more precise descriptions and discussions on these matters.

4.5.3. Temporality as a lens for moving HCI research forward
 In going through the 4×4 matrix, we noticed that although some areas are heavily researched (e.g. empirical studies of how people organize their work hours around computer systems), this matrix also illustrates some ‘under researched’ areas. For instance, there are almost no studies that take on a design approach in the studies of humans. There are, of course, some exceptions, for instance, studies of call centers where researchers examine if call center operators can do more things at the same time or be more productive (work faster) (see the studies by Koole et al., 2003, and Park, 2007). Other examples include empirical studies of human–human multitasking dialogues where people perform multiple verbal tasks overlapped in time and how to optimize for conversants to switch from the ongoing task to a real-time task (Yang et al., 2008). Still, most of this work is more concerned with human cognitive capabilities and its limits than learning more about aspects of time and temporality in HCI.

Further, we found very few studies that applied a design perspective on how the field of HCI has changed over time (intersection of design/over time, 7 in **Table 2**). Of course, it may be a consequence of the fact that taking a design approach to the ‘over time’ aspects is quite challenging and would require a type of longitudinal design experiments that we have not seen in the field so far.

As a summary, time and temporality has both been ‘over researched’ and ‘under researched’ in HCI. There are so many

empirical studies and experiments performed where time is a central factor that it is almost impossible to see any clear research gaps or blind spots on that map, and the under researched area should maybe not be interpreted as ‘missed spots’ on the map. Instead, the 4×4 matrix shows the contours of the time and temporality research area in HCI, and the main implication from this might be to not strive to balance out or expand the existing research to all of the areas in the 4×4 matrix but rather to continue along the direction that *stands out* and along the *ongoing shifts* we have identified. In the next section, we will expand a little bit further on the overarching implications from this study.

4.6. Implications

It should be noticed that our study of the existing HCI research literature only shows what has been done. It does not tell us where to go. We can of course go deeper into the literature, cover more studies and in more detail seek to identify trajectories of emerging and declining areas, areas that expand or contract and approaches that grow in use or decline. Still, one such more in-depth analysis of the whole field of HCI does not tell us what HCI research need to do or should engage with. It should again be said that our study did not intentionally set out to identify trends and changes over time, or to quantify the different amounts of work done on time and temporality in HCI. This would have required different methods and tools of a larger corpus. Instead, our initial purpose was to examine how the field has addressed time and temporality to this point—to map out the landscape of different studies (i.e. ‘what’) and the current approaches taken (the ‘how’ dimension). This means that we cannot present a complete summary of the field, nor any normative implications that are solidly grounded in one such analysis.

While it is always hard to generate implications from observations (to move from ‘is’ to ‘ought’, or from descriptions to normative suggestions), we believe that our findings still lead to some questions that HCI research should engage with. In the following sections, we cover these from the perspectives of a first, second and third wave of time and temporality studies in HCI, the importance of the 4×4 matrix in moving forward and a shift from things to events that might have implications for further research.

4.7. First, second and third wave of time and temporality studies in HCI

Based on our study, we propose that the field has moved from a first wave of time and temporality studies in HCI (characterized by a focus on time optimization; such as studies of efficiency in task performance, multitasking, interruptions, etc.), towards empirical studies on temporality as an fundamental dimension of practice that can be seen as a second wave of time and tempo-

rality explorations in HCI (characterized by a methodological and design-oriented attitude toward time and temporality in HCI). Accordingly, we found recent studies that contribute new designs built around temporality as a central component of the design.

Moving forward, we see emerging contours of a third wave. In this third wave, there is an interest in theorizing time and temporality and attempts to explore new conceptualizations of time and temporality. Based on this, we may see more design projects that rely on different (theoretical) conceptions of time. We are already seeing this around the notion of slow technology. This research has to deal with new conceptualizations of time itself and how these conceptualizations can be manifested in actual designs. We can also see attempts to address traditional work practices with new understandings of time and temporality. Online, offline, synchronous and asynchronous work has been primarily addressed through empirical studies, and we anticipate that we will see more design-oriented research taking on this area based on new concepts of temporality.

4.8. The importance of the 4×4 matrix in moving forward

In our analysis, we have looked at *what* has been studied and *how* it has been studied, and along these two dimensions we have presented a 4×4 matrix with categories that describe existing strands of research on time and temporality in HCI. We acknowledge that there might be other ways to portray existing research, but we think that categories that closely relate to the fundamentals of HCI, i.e. in relation to ‘Human, Computer, Interaction, over Time’, is a reasonable first step before we can do a more detailed, complex or in-depth analysis including trends, stages and developments over time, or critical studies aimed at examining how for instance politics and power has played out in the field of HCI over the past few decades. Hopefully, the 4×4 matrix as presented in this article can initiate such further studies. We also see potential in using this 4×4 matrix to explore how other topics has played out in the field of HCI over time. Finally, there are also opportunities for future work that moves beyond this 4×4 matrix. For instance, by taking ‘human–computer interaction’ as the unit of analysis and considering the temporal dimensions that shape and emerge from these interactions between humans and technology in socially situated, and culturally embedded, ways.

4.9. A shift in HCI research *from things to events*

On a more fundamental level, we suggest that the current development, and the increasing focus on temporality, denotes a shift in HCI research *from things to events*. However, it is not a shift *away* from things, it is rather a shift to study *both* things and events.

With time and temporality as the analytical lens, the focus changes from objects, things and artifacts to the flow, pace and rhythms of information, communication and computing. In this shift, time and temporality also shift from serving as a secondary or implicit dimension or aspect of HCI to more clearly denote a particular strand of research in HCI where ‘time’ is the core concept. Further, we notice how this shift has also implied a shift in approaches and the object of study. From empirical studies of how work is temporally arranged around and with computers, we are now moving toward design approaches taken to time and temporality as design materials in the further exploration of time and temporality in HCI. This is not only a shift, but given the increasing interest in this approach as evidenced from our literature study, we suggest it marks the beginning of a new period in the history of HCI research.

5. CONCLUSIONS

In this article, we have explored how HCI research has approached ‘time’ and ‘temporality’. Based on a corpus of published work, we have identified and presented how time and temporality can be displayed along the axis of *what* has been studied and *how* it has been studied. For the axis of *what* has been studied, we have structured our analysis around the HCIOt model (Human–Computer Interaction over Time), and accordingly, we have focused on HUMANS—on the pace and rhythms of work and life, COMPUTERS—fundamental principles for computing and visualizations, INTERACTION—temporal explorations of interaction and TIME—phases in time and historical perspectives on time and HCI. This HCIOt model enabled us to define the *object of study*, i.e. *what* has been studied so far. For the second axis, we focused on *how* this object of study has been explored in HCI research. With this focus, we noticed four categories that emerged from our literature study: empirical approaches, methodological approaches, theoretical approaches and design approaches to time and temporality in HCI.

Based on the two dimensions of *what* has been studied and *how* time and temporality has been studied in HCI, we created and presented a 4×4 matrix that illustrates areas that have been substantially explored and areas that are still under-researched.

On a more general level, we suggest that our work adds to the establishment and the development of time and temporality-oriented studies in HCI as a particular strand of HCI research. Further, we suggest that an understanding of the relation between temporality and interaction has wider implications for HCI research. A focus on temporal aspects of HCI leads to methodological implications for how to capture and understand interaction, no matter if it concerns rapid turn-takings or interaction over long periods in time. We anticipate that the interest in temporality in HCI research that we have observed will continue to grow and lead to exciting new research questions and challenges.

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