Cultivating Altruism Around Computing Resources: Anticipation Work in a Scholarly Community

JOHANNA COHOON, University of Utah, USA
KAZI SINTHIA KABIR, University of Utah, USA
TAMANNA MOTAHAR, University of Utah, USA
JASON WIESE, University of Utah, USA

User research for scientific software can inform design and account for the unique concerns of academic researchers. In this study, we explored the user experience on a testbed for cloud computing research, CloudLab. Through 15 semi-structured interviews and observation, we observed the importance of time as a resource to system users. We observed CloudLab users strategically coordinating their time on the platform with other users, navigating the constraints of publication and other academic deadlines. Surprisingly, we found that this coordination may involve altruistic behaviors where users share time on CloudLab that had been allocated for personal use. In light of prior CSCW literature on how actors seek to harness time, we propose concrete opportunities for design interventions. Our strategy across all possible interventions is to increase users' awareness of the rhythms affecting their peers' platform use, allowing coordination based not just on knowledge of CloudLab reservations but also users' progress toward deadlines. The implications of this work inform the design of other similar cyberinfrastructure systems in science where users independently coordinate use of resources.

CCS Concepts: • **Human-centered computing** → *Field studies*; **Computer supported cooperative work**; **Empirical studies in collaborative and social computing**; *Visualization systems and tools*; • **Social and professional topics** → User characteristics.

Additional Key Words and Phrases: cyberinfrastructure, cloud computing, scientific collaboration, science studies, coordination, time, temporal rhythms

1 INTRODUCTION

CSCW research has often explored the work involved in developing and sustaining scientific software, theorizing about its processes and challenges [6, 15, 17, 27, 32]. While many of the findings from this body of literature can be applied to other contexts, an important theme is the relationship between academia and actors' behavior. Without scholarly credit, certain software work and knowledge sharing is disincentivized [15, 32]. Such insights can inform development approaches but they also beg the question of how the scholarly context might affect software use.

Authors' addresses: Johanna Cohoon, hannah.cohoon@utah.edu, University of Utah, Salt Lake City, UT, USA; Kazi Sinthia Kabir, kskabir@cs.utah.edu, University of Utah, Salt Lake City, UT, USA; Tamanna Motahar, tamanna.motahar@utah.edu, University of Utah, Salt Lake City, UT, USA; Jason Wiese, jason.wiese@utah.edu, University of Utah, Salt Lake City, UT, USA.

Proc. ACM Hum.-Comput. Interact., Vol. 7, No. CSCW2, Article 336. Publication date: October 2023.

336

If scientific software development is meaningfully different from that in commercial settings, how does being a scientific researcher affect the user experience?

We report results from a user experience study of a national cyberinfrastructure project that provides cloud computing services to academic researchers, CloudLab (www.cloudlab.us). Users of CloudLab are primarily networking, security, or database researchers. Through this study, we identified a significant opportunity for improving the user experience while addressing the needs of the system developers. We suggest that by using visualizations to raise awareness of the academic deadlines affecting colleagues' use of the system, conflicts over resources can be reduced and use of CloudLab can be "gracefully balanced" [12] across time. CloudLab developers sensitized us to possible conflicts around time when briefing us on their approach to designing the platform. The developers indicated that they hoped to broaden access to CloudLab's computational resources by discouraging users from hoarding them for long periods. However, subverting developers' expectations, CloudLab users often told us that they altruistically free up computational resources as soon as they can.

To account for this surprising finding we turned to analyses of time in CSCW, drawing on the language of anticipation work [30], collaborative rhythms [16], and temporal trajectories and horizons [26]. Using these concepts, we describe in abstract terms how CloudLab users coordinate their use of the system with one another while attempting to keep up with the beat of academia. We go beyond providing empirical examples of these concepts, using them to inspire testable design interventions that can encourage more altruistic practices.

The remainder of this paper is organized as follows. We first introduce the literature that guided our analysis, describing known strategies for harnessing time including the use of visualization. We then present our research site, CloudLab (Section 3), followed by our data collection and analysis methods (Section 4). Next, in our results (Section 5), we outline two major themes in our data: time as a valued resource and resource sharing. We report how each theme relates to time management on CloudLab and the academic environment our participants work within. In our discussion (Section 6), we interpret these findings in light of prior work and propose design interventions to foster the altruistic behaviors observed. This research makes three contributions to move the literature forward:

- Provide evidence of the interaction between academic deadlines and coordinative (anticipation) work on scholarly infrastructure
- Use existing taxonomies and concepts to describe this interaction in terms of time, expanding the use of the term "temporal trajectory" [26]
- Propose concrete, testable design interventions to cultivate an "alternative temporal experience" [19] where time on CloudLab is shared among users with greater facility

We conclude by showing that our findings resonate with similar research and have applicability to other scholarly cyberinfrastructure.

2 LITERATURE REVIEW

In this section, we review several ways time has been conceived of in CSCW research, presenting it as an enacted, sociotechnical structure. The literature has described how actors align different temporal rhythms to coordinate their actions. This alignment work, also called anticipation work [30], conjures up an imagined future. Prior work suggests that design can be used to support anticipation work and that data visualization in particular might help cultivate useful, collective understandings of time. Such design interventions enable coordination by increasing awareness of the work context, an approach well established in CSCW literature [11]. We discuss these points while acknowledging

that anticipation work is also mired in values—to seek a future is to assign it priority over other possibilities.

In subsequent sections, we describe our research site, qualitative methods, and the results of our thematic analysis. In our discussion, we address how our results relate to the literature presented here. Notably, our findings show that time was enacted as a resource valuable to multiple conflicting futures imagined by CloudLab users—one of which was unexpected though welcome by the system's developers. We posit that an existing data visualization might be key in the anticipation work to bring about this future (one we characterize as altruistic) and discuss other ways to encourage prosocial coordination among users.

2.1 Conceptualizations of Time in CSCW

In CSCW studies, time is understood to manifest in multiple ways simultaneously. It is recognized by researchers through patterns of behavior; rhythms emerge with repetition. Time is not only manifested through a technological medium, it is also enacted through social practices.

Asserting this sociotechnical perspective, Lindley stresses that the "temporal experience" is "upheld partly through the interface and partly through social conventions" [19]. This take draws on Orlikowski and Yates's [22] argument that time is a structure in Giddens's [14] sense: it influences behavior and is also influenced by it.

Lindley [19] builds on prior literature to describe concepts like "clock time." Clock time is a set of practices that spur from the continuous flow of time on a metered, forward trajectory. Lindley distinguishes this from the "digital time" conveyed through social media services like Facebook. Unlike clock time which progresses at regular intervals, Lindley suggests that digital time perpetually maintains the presentation of "nowness." For example, while clock time may tick away second by second to indicate forward movement, digital time on social media constantly projects the present by displaying currently trending topics and recent content. Lindley argues that this design choice influences users' behavior, encouraging them to post new, rather than old, content.

While maintaining a sociotechnical perspective, other authors have posed different conceptualizations of time. In their paper, Jackson et al. [16] discussed several collaborative rhythms (i.e., conceptualizations of time) among researchers: organizational, infrastructural, biographical, and phenomenal. For Jackson et al., who studied ecologists, organizational rhythms are patterns of work and collaboration that emerge alongside institutional and organizational structures like the timing of academic holidays. Infrastructural rhythms are patterns of work and collaboration that emerge around the tooling which supports the work, e.g., the timing of software updates and the practices they imbue. Biographical rhythms are the patterns of personal change, according to Jackson et al. They note that "patterns of interaction may change radically as key participants undergo certain kinds of life transitions" [16]; a successful tenure review, for example. Finally, phenomenal rhythms are presented as patterns of practices that emerge around any other concern of interest. Jackson et al. draw particular attention to natural and regular rhythms like changing seasons as well as sporadic events like volcanic eruptions. By recognizing these four rhythms, the authors discuss how actors collaborate to align the rhythms when necessary. In Steinhardt and Jackson [29], the authors build on Jackson et al. [16] to emphasize how the activity of planning can elevate or obscure rhythms, noting the study of planning as a useful way to explore rhythm alignment.

Extending this line of research, Chen et al. [8] also sought to unpack time as a collaborative concept, hoping to improve the design of HPC systems through a nuanced understanding of their relationship to temporality. Chen et al. drew a distinction between "machine" and "human" time, likening this to a conflict between Jackson et al.'s [16] infrastructural rhythms and biographical rhythms. Machine time, Chen et al. describe, is time spent using an HPC node (i.e., a high speed

server). The beat of machine time is dictated by how hours of HPC node use are allotted, used, forgone, and reallotted. Machine time would ideally be a constant rhythm of use by one researcher before a transition to another researcher. While technically possible, Chen et al. [8] argue this infrastructural rhythm is constrained by "human time issues" that impede the optimal use of the HPC system.

Although this literature clearly makes the point that time is not a simple concept, some terminology like "clock time" and "machine time" might imply that technology provides an ideal interpretation of time that human sociality complicates. However, (like humans) technical systems do not necessarily enact time in a straightforward manner. Lamport [18], for example, shows that when system processes are ignorant of one another, their order of events is ambiguous. "In a distributed system," Lamport [18] explains, "it is sometimes impossible to say that one of two events occurred first."

In our discussion, we draw on these conceptualizations of time to describe the multiple ways that time is enacted on CloudLab.

2.2 Harnessing Time

The multiple manifestations of time described in the literature above represent "conflicting regimes of lived time" [33]. To achieve goals, time must be harnessed and these regimes must be aligned. Jackson et al. [16] provide an example:

> "*The Martian day is precisely 2.7% longer than that on Earth. To make up the difference, and to not lose crucial sunlight needed to recharge the Rover's solar batteries, NASA makes the decision to put its Rover team on Mars time for the duration of the project. Members of the project team are to live, literally, on Mars time, organizing their work and lives around a day 24 hours and 39 minutes long.*"

In Jackson et al.'s [16] language, NASA's strategy for problem solving showcases the alignment of organizational and biographical rhythms with phenomenal ones like planetary motion. While it accomplished their goal, it is notable that this solution presented still other challenges like how to maintain personal relationships across interplanetary time shifts. "Temporal alignment is therefore a strategic and creative activity," wrote Jackson et al. [16].

Parmiggiani et al. [24] further demonstrate the difficulties that may be involved in temporal alignment. The authors studied infrastructuring [28] by an oil and gas company seeking to enable real-time monitoring of oceanic life. To facilitate multiple stakeholders' real-time monitoring of underwater phenomenal rhythms, Parmiggiani et al. [24] found that the company had to adjust social practices and technical systems in many ways. A key strategy for achieving alignment with minimal disruption was bootstrapping; Parmiggiani et al. saw that the oil and gas company began by involving existing technologies and a limited stakeholder group, then grew their efforts to introduce more stakeholders, new technology, and new social processes. This approach strategically limited the purview of the real-time monitoring initiative, such that the temporal alignment of monitoring system users was accomplished gradually.

Some other qualitative work has also explored the information and strategies that workers use to accomplish temporal alignment. Providing a simple example, Delfanti [10], shows how researchers in the field of high energy physics align themselves to an infrastructural rhythm dictated by the preprint service arXiv (https://arxiv.org/) in order to bolster their reputation:

> "*Papers are posted daily [on arXiv.org]....Furthermore, physicists know that papers in the top or bottom tier of the day's listing receive more hits and are more likely to be detected....Submitting a paper at 4:01 p.m. ensures that it will be among the first ones in*

the next group of articles. Physicists race to submit their most important papers at the right moment in order to meet the need for increased visibility."

Reddy et al. [26], who studied collaborative temporal work through an ethnography of a surgical intensive care unit (SICU), provide another example of worker's strategies. Furthermore, the authors developed three analytical constructs to describe how actors like surgeons and nurses coordinated their behaviors to provide effective medical care. These constructs are temporal trajectories, temporal rhythms, and temporal horizons and they can be understood as aids for "temporal alignment," as Jackson et al. [16] describe it. We summarize these constructs presently.

"Temporal trajectories" are heavily tied to the SICU context. Reddy et al. [26] use the term to refer to where a patient stands in terms of their recovery. A temporal trajectory is a status which implies a certain time to recovery. For instance, Reddy et al. give the example of a patient being "post-op 3 days" [26]. When contextualized within other knowledge of the patient and medicine, a surgeon can use the three-day status to understand how close to discharge the patient is; they establish a temporal trajectory.

Reddy et al. [26] present "temporal rhythms" as the patterns that emerge across multiple temporal trajectories. The authors report the SICU they studied had many ongoing temporal rhythms such as the procedures for nurses' shift changes or the turnaround times for regular and urgent lab tests. Temporal rhythms are emphasized as a collective practice, while temporal trajectories are individual.

Finally, "temporal horizons" are similar to trajectories in that they are goal-oriented and concerned with individuals rather than groups. However, whereas the latter is a sensemaking tool for medical providers assessing patient conditions, temporal horizons are more general. A temporal horizon is how a worker "organizes [her] jobs based on her knowledge of when she has to finish them in order to prepare for upcoming activities" [26]. The authors characterize horizons as being flexible or inflexible and close or distant. Close horizons mean that a deadline is approaching. Flexible horizons mean that work need not occur at a specific point in time. Recognizing the characteristics of a temporal horizon allows workers to do alignment work, approaching the horizon strategically. For example, Reddy et al. saw that as a shift change approached and the horizon became close, nurses sped up their work to accomplish their goals on time.

Many authors have noted that attempts to harness time are not value-neutral. Reflecting on the sociotechnical practices of Silicon Valley, Wajcman [33] suggests that time is often thought of as "an individual resource to be husbanded, rather than as a relational, collective accomplishment" [33]. She contends that digital calendars and the plethora of resources a paying individual can use to carve out more time (e.g., food delivery and cleaning crews) attempt to wrangle time for personal benefit and workplace productivity. Wajcman [33] cautions against the constant pursuit of efficiency. Similarly, Puig de la Bellacasa [25], argue that the field of soil science has been subject to the hegemony of agricultural productivity, a logic which conceives of soil as a consumable for humans rather than as a living ecosystem that people participate in. This dominant logic views "maintenance and repair of ecological life" as "wasted time" despite its environmental benefits, instead favoring the use of technology and innovation to rapidly produce abundance [25]. Mazmanian et al. [20] further draw attention to how harnessing time involves questions of power and which activities "are given priority in any one moment."

While sometimes controversial, it is this idea of harnessing time that CSCW and HCI researchers seek to take advantage of. Given that we enact temporal rhythms through our behavior and technologies [22], we ask how can those be modified to "reshape the temporal patterns that form the backdrop of everyday life" [19]? We take up this question with respect to CloudLab in our discussion section.

2.3 Anticipation Work

Any approach to harnessing time can be understood as what Steinhardt and Jackson [30] refer to as anticipation work:

> *"Anticipation work is the realized, pragmatic and attainable ways actors move toward some imagined future (ex. designing protocols for handling specimens, formalizing data standards, establishing support groups)."*

The authors outline several characteristics of anticipation work, defining it as work that "asserts normative claims" and "is key in scaling between local and institutional forms" [30]. Steinhardt and Jackson, who studied the US National Ecological Observatory Network (NEON), demonstrate how anticipation work can bridge local and institutional practices through a quote from a staff scientist they interviewed:

> *"Because of the breadth of those sampling activities, plants, insects, mammals, aquatic environments and so on, you're sourcing information from a variety of different communities. And even within each of those communities, there are no standard methods of practice. One PI and another PI will differ quite strenuously about the right way to do it, and so there is no standard within the community of practice."*

NEON engaged in anticipation work when they brought together representatives of various disciplines to develop standards of practice and when they trained researchers on those standards. This anticipation work served to make data from multiple sites reliably comparable, solving the problem Steinhardt and Jackson's [30] interviewee described.

Anticipation work is evident in findings from many sociotechnical analyses of temporality. For instance, Palen [23], who studied group calendars in the workplace, describes the practice of "scheduling defensively": "Time can be protected even further by using a fake appointment to disguise work time, and minimize the possibility of being asked to attend a meeting instead." In this case, fake appointments anticipate a future with many demands and create one where personal time is protected.

Anticipation is understood to be an abductive process oriented toward optimization [9]—actors tack between information gathered about the past and "probabilistic anticipations" [2] about the future, seeking a desired outcome. This concept of a preferred future intertwines anticipation work with ethics and values [2, 9, 33].

The concept of anticipation work informed our analysis substantially. Later, we describe how our participants and other CloudLab users anticipated the resources that might be available in the future and independently coordinated to optimize the time available to them for experiments.

2.4 Designing for Anticipation

A common strategy to support anticipation work is to provide the information necessary for the abductive process Adams [2] describes; this approach is backed by decades of CSCW research on coordination and awareness [11]. Palen [23], for instance, saw that event coordination became easier between employees when they used a groupware calendar system (GCS) that made coworkers' availability publicly visible—the GCS depicted a probable future that allowed anticipatory action.

The visibility offered by the GCS Palen studied is one example of a dominant approach to designing for anticipation work: Visualizations are thought to reduce the cognitive burden of temporal alignment, thereby assisting in decision making and collaborative work [3, 5]. Parmiggiani et al.'s [24] study provides another example; the web portal that displayed the real-time oceanic data was meant to support oil drilling engineers' decision making by mapping existing infrastructure and subsea terrain.

Aragon et al. [3] have studied the effects of visualizations for astrophysicists. The authors visualized the path of astronomical objects on a two-dimensional map, transforming complex three-dimensional data to make it simpler for scientists to make quick decisions about what to measure and when. Clouds may move and planetary bodies shift, so instruments may need redirection. Aragon et al.'s [3] visualization replaced an individual's ad hoc interpretation of the effects of time with a standardized map of them.

Several studies have explored the use of visualizing colleagues' work activity (e.g., [5, 13, 21]). Morrison-Smith et al. [21], for example, built a system to track and display computer activity, arguing that awareness of others' work rhythms is useful for collaboration and reducing anxiety. Similarly, Begole et al. [5] visualized coworkers' activity traces to create a shared awareness of time that would aid in scheduling and timely communication. Such a visualization can surpass the ability of "calendar time" to indicate availability by also accounting for other rhythms. For example, Begole et al. saw that some participants' activity visualizations revealed their entanglement with the infrastructural rhythm [16] of the local bus schedule [5]:

> "The start and end of the day... have a stepped pattern with an interval of approximately 30 minutes between steps occurring at around 15 and 45 minutes past the hour. This pattern has useful implications if you are trying to reach this person because, for example, if he is not active at 8:20, you can infer that he is not likely to become active before 8:45."

Visualizations are thus informational tools that can be used to align different temporal rhythms [16] by providing "awareness information" necessary for coordination [11]. As Morrison-Smith et al. [21] and Begole et al. [5] sought to show, shared use of such a tool can cultivate a better understanding of "collective" time [19]. Furthermore, design can be used to nudge individuals toward certain actions, encouraging them to spend time in one way or another [31, 33]. In our discussion, we address how visualizations can be useful for anticipation work on CloudLab and other platforms.

The literature described above presents anticipation work as action toward a certain goal. Ethnographic studies show that this work can fall into particular rhythms, but these are highly context dependent. Although design may be effective in aligning conflicting rhythms and supporting anticipation work, a thorough understanding of users' values and use context is important. We now turn to the context for our own research and describe CloudLab, the system whose use we studied.

3 RESEARCH CONTEXT

CloudLab is a testbed facility for researchers who need to construct clouds of their own. Cloud computing in general provides "on-demand network access to a shared pool of configurable computing resources...that can be rapidly provisioned and released" [4]. According to its developers, using CloudLab "provides more control, visibility, and performance isolation than a typical cloud environment, enabling it to support work on cloud architectures, distributed systems, and applications" [12]. These capabilities are meant for scholars who study networking, security, and databases. The testbed also proves useful for researchers who simply need more computational power than what their local hardware can provide. A popular alternative to CloudLab is the commercial cloud option, Amazon Web Services (AWS).

CloudLab gives access to more than 2000 nodes across a federated network of hosts at no cost to users [12]. By choosing nodes (i.e., servers) that meet their hardware needs, connecting these to one another, and configuring them with appropriate software dependencies, CloudLab users construct their own clouds (see example in Figure 1). Most nodes are located at three universities in the United States. Each of these host sites specializes in hardware fit for certain purposes. The site whose resource availability is displayed in Figure 2, for example, is useful for analytics and high-performance workflows [12].
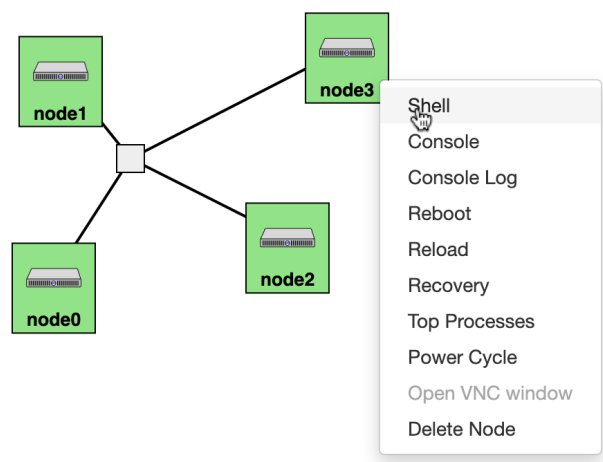
Fig. 1. A four node cloud constructed in CloudLab. Options are shown for node3; this range of options is available for each node in the network. Clicking "shell" would allow a user to open a browser-based command line tool and then connect directly to an individual node via SSH. Once connected they can install dependencies or monitor processes in an experiment. Unlike in some network diagrams, distance between nodes is meaningless here.
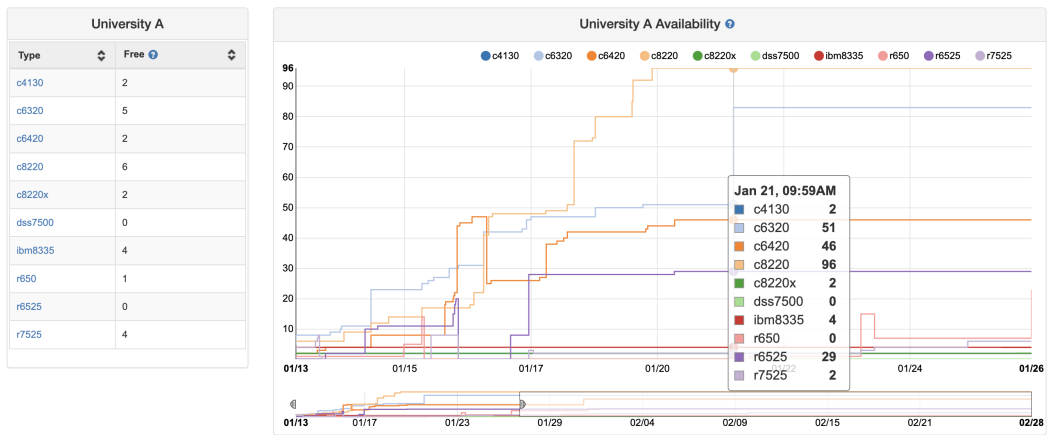

Fig. 2. A resource availability graph for University A, one of CloudLab's node hosts. The table on the left indicates currently available nodes of multiple hardware types (e.g., c4130). The line graphs on the right display how hardware availability changes over time. CloudLab users leverage these graphs to plan their experiments.

3.1 Experiments, Reservations, and Extensions

To conduct a study with the CloudLab testbed, researchers must request the necessary nodes and use those to establish the computational environment in which they will execute their study. In summary, this process involves the user:

(1) Creating or logging into a CloudLab account that is associated with a research project
(2) Choosing or creating a profile that specifies the type of hardware and some software needed to run the experiment
(3) Choosing the number of nodes needed and the site that hosts them (e.g., University of Utah, University of Wisconsin-Madison, Clemson University)
(4) Specifying the dates when the nodes will be needed

These steps may be performed in different orders. For example, nodes can be reserved for specific dates without choosing a profile to instantiate on them.

Experiments (i.e., profiles instantiated on allocated nodes) expire but can be extended. When a researcher seeks to extend for a short period of time, this is usually granted automatically. However, longer extensions that last weeks or months require administrative review. Researchers provide a reason for their extension request through a form. While an experiment is "up" the user can execute scripts that collect data. This data might be, for example, the number of operations performed per second, a measure of system throughput.

Nodes to make up an experiment's cloud can be requested for now or the future. As Duplyakin et al. [12] describe it, "A reservation is not an experiment scheduled to run at a specific time, but a guarantee of available resources at that time. This allows users to run many experiments either in series (e.g., to test different scenarios) or in parallel (e.g., one experiment per student in a class)."

3.2 Balancing Traffic Across Time

Because CloudLab is free to use, its developers have taken a different approach from commercial cloud systems to their reservation system. Commercial systems like AWS imply access to as many nodes as you can pay for, while CloudLab clearly conveys the limits on its available nodes, signaling how many nodes of each type are available at a given time on a resource availability graph like that shown in Figure 2. It is, therefore, important that a steady flow of nodes becomes available as others get reserved. "If users' needs frequently cannot be satisfied due to insufficient availability, those users will likely move to other facilities," write Duplyakin et al. [12]. While most reservations appear to use the computational resources requested, Duplyakin et al. [12] have found that 12% of all reserved CloudLab node hours go unused, suggesting opportunity for improvement.

Duplyakin et al. [12] introduced the reservation system as an alternative to economic incentives that could also balance traffic across time. The reservation system and resource availability graphs were designed to help users anticipate when they can complete their work on CloudLab. They state that the feature was a bit of "social engineering" [12] to ensure enough nodes were available at all times. By visualizing the future availability of CloudLab nodes, its developers sought to reduce the competition for nodes brought on by conference deadlines and end-of-semester work. Because these graphs cannot anticipate extensions to reservations, however, their predictions about future availability are not necessarily accurate.

4 METHODS

The present paper reports results from a larger project studying the user experience of CloudLab. The larger project is focused on improving the user experience as well as increasing the reproducibility of experiments conducted on CloudLab.

We conducted 15 remote interviews with CloudLab users from ten universities. Only one participant was from a CloudLab host university. All but one international participant worked or studied at a US university. We sought to include both highly experienced and inexperienced users, but had difficulty recruiting participants for the latter group. Our results, therefore, reflect the behaviors of CloudLab users who are familiar with the system. Aside from that challenge, collecting

data remotely significantly facilitated recruitment and enabled us to capture data to represent CloudLab's geographically distributed user population.

Interviews were conducted over video calls and were recorded with participants' consent. Each of these interviews were conducted by at least two researchers; one led the session and the other took notes and asked follow-up questions. We transcribed these interviews using an automated transcription service (otter.ai).

Interviews began with a remote observation session where the participants shared their screens and the researchers observed as participants went about the usual tasks they undertake on CloudLab. Following this typically 30-minute observation session was an interview that generally lasted another 30 minutes. Throughout the total hour, participants described how they instantiated experiments on CloudLab, monitored their progress, saved their data, and reported their results. Due to CloudLab's interest in supporting reproducibility, we also asked about any experience with artifact sharing. Artifact sharing, as implemented by the Association for Computing Machinery (ACM), involves sharing research materials like code and data for external review [1]. In light of a review, an article may be awarded a badge to show it has an artifact that has been evaluated, made available, and/or validated the published findings.

Interviews were analyzed using reflexive thematic analysis [7]. This process was conducted iteratively and our analysis evolved in light of the team's ongoing discussions. Thematic analysis involves labeling or coding qualitative data to "identify a feature of the data (semantic content or latent) that appears interesting to the analyst" [7]. Those codes are then reviewed, combined, and broken up to identify prominent themes in the data.

Each interview was coded by at least one author in ATLAS.ti. Coders regularly met to discuss their work. During such discussions it was common to provide new evidence for emergent themes as well as to discuss exceptions to those themes. After seven interviews were conducted, the coders met to create a list of focused codes that would be applied to the remaining interviews. While the list evolved as we coded more interviews and continued with open coding, this list of focused codes ensured that each member of the research team attended to the same concepts. In practice, we used these focused codes as broad labels that preceded specific details. For example, the focused code "Resource availability" was applied through the codes "Resource availability: deletes reservation to free up resources" and "Resource availability: Bare metal servers of CloudLab not feasible for a bigger class." Other focused codes included "Feeling frustrated," "Repetitive task," "Managing time," "Making a reservation," "Troubleshooting," and "Monitoring experiments," among others.

By reviewing the coded data and notes from prior discussions, and through affinity diagramming, the authors organized the codes into larger themes. Given our interest in user experience, many of these themes represented common actions that study participants took on CloudLab, e.g., monitoring experiments or checking the resource availability graphs. These themes were iteratively refined through more diagramming and memoing. For example, we saw that quotes labeled with codes like "Resource availability: makes sure resources are deleted after experiment," "Artifact evaluation: provides detailed instruction," and "Publishing: work in progress stays private" all related to sharing resources of different kinds. As we analyzed our data, we remained sensitized to the concepts in our literature review and attuned to the CloudLab developers' concerns about maintaining good node availability. Ultimately we developed seven main themes: Time as a resource, Resource sharing, Learning CloudLab, Backing up data, Publishing, Security, and Cognitive burdens. The first two of these were well saturated and are, therefore, the results presented below.

5 RESULTS

Through this iterative analytical process, we identified two themes of importance among our data. We present these themes here, describing how they were enacted by our participants and the nuances

that bring them together. In summary, we saw that time is a valued resource whose expenditure can be optimized through strategic resource sharing. Who benefits from such optimization depends, however—CloudLab users may be taught to free up nodes for others' use whenever possible, but concerns around timely progress to deadlines may curb altruistic behavior. Later, in our discussion, we describe these findings in terms of anticipation work and temporal rhythms, drawing from the literature reviewed above to paint CloudLab use as involving the alignment of social and technical temporalities. This alignment, we argue, can be further supported through design intervention. Through these interventions, scientific software like CloudLab can account for the unique context of its users.

5.1 Time as a Valued Resource

The first theme we present from our research is time as a valued resource. We saw that our participants placed a high value on time through their dismay at "wasting" it and their strategies for working efficiently. Behaviors like reusing resources and requesting extensions for experiments showed that it was important to our users to gain time on CloudLab and use it productively by collecting data. Similarly, their negative reactions to wasted and lost time also indicated its value. Time spent on CloudLab was often valued because it was expected to culminate in a publication. Our participants understood the value of CloudLab time to other users as well and sometimes sought to share any extra that they might have.

5.1.1 Reducing wasted time. Our participants described repetitive tasks and periods of waiting as frustrations. When dependencies (e.g., required software packages) were being installed or a node needed to be rebooted after a failure, participants disliked the minutes or hours they had to spend waiting for the process to complete (Figure 1 shows how to reboot a node). For a very short experiment like P1's, these processes could take a third of their CloudLab time:

> *"If we look back at the log, you can see that it's just rebooted….It takes a really long time to do that. It's like, three to four minutes just to reboot. Which is kind of funny, actually. Because the whole experiment only takes like eight minutes."*

To avoid wasting time, participants used multiple strategies. During waiting periods, for example, they often turned to other tasks like processing emails. P1, for example, let their experiment stall and did not consider this wasted time because they spent it another way. P1 said,

> *"I just let it hang because I was working on something else."*

Other strategies to avoid wasting time were also apparent. For instance, to skip the wait for human approval of a reservation request, participants often requested short experiment periods that could be extended automatically rather than attempting a single long reservation that would need more written clarification and an admin's review. We also observed users speeding up tedious and repetitive setup work through automated scripts and the use of disk images, as discussed below.

5.1.2 Reusing resources to optimize time use. We observed that participants strategically optimized their use of time by reusing resources when running experiments. For example, CloudLab is designed to support replication through features like profiles. Our interviews and observation showed that users took advantage of this: they cut down on the work needed to instantiate multiple similar experiments by reusing the same CloudLab profiles multiple times. "Most of the time we use the same profile," P4 told us.

It was also common for users to reuse software installation and experiment instantiation scripts that they or a labmate wrote. P4 said,

> *"We just clone our repository that has the setup scripts that we require, and execute those setup scripts."*

This ensured that the same software environment was used and the same actions were taken across experiments without the time consuming manual input of each command with each replication. If P4 did not clone the repository, they would need to use a more time consuming approach. Disk images too were reused in the name of efficiency and reproducibility. Reusing resources saved valuable time.

Sometimes reusing resources might require editing those resources or engaging in repetitious behavior–our participants described abandoning those practices because they were not time savers. P3, for example, told us that the configuration choices they made for their cloud rendered CloudLab's dataset reuse feature "a little bit tedious," so they stopped using it.

5.1.3 Undesirable consequences of losing time. Participants also communicated the value of time as a resource when describing the consequences of losing it. When time on CloudLab was unexpectedly lost, the downstream consequences could be significant. Participants described several scenarios where they had expected to spend time using the CloudLab testbed only to find it unavailable to them. For example, one participant was asked to surrender their experiment time to a labmate by their advisor, causing them to miss their publication deadline. "My advisor made me delete my reservation," P9 told us. Consequently, they had to submit to a different conference with a later deadline. After this experience P9 learned strategies from their "resource hawk" labmates like "push[ing] in as many reservations as I can" to ensure P9 would not face a shortage of available CloudLab time in the future.

On other occasions, nodes in a user's cloud might fail without warning or the researcher may forget that an ongoing experiment needs more time. In these cases, the expected progress is arrested and the researcher must troubleshoot and restart the study. P8 spoke from experience:

> "Sometimes I forget to extend my experiments...I have been in incidents where all of my work has been like, deleted because the experiment is not extended, or expired. And unfortunately, there is no like a backup period. Or maybe, CloudLab, they don't have to have the recent data somewhere. So I lost all of my work and I have to do that again."

Depending on the time to deadline—usually a publication deadline—this lost time may be more or less precious. Lost time may require repeating a period of work like in P8's case; the repetition is perceived as waste.

5.2 Resource Sharing

Researchers in our sample considered time as a valued resource and adopted practices like resource sharing to optimize their use of time. During observation and interviews, we saw that such resource sharing was a nuanced practice. While some users altruistically shared CloudLab time by deleting their node reservation, competition for nodes within a lab may still be fierce. Knowledge gained through experience and research may be more willingly shared, especially within a lab, and the collaborative code development platform Github (https://github.com/) was commonly leveraged to that end. However, our participants limited sharing such research artifacts prior to publishing in part because they believe sharing in-progress work to be a risk.

5.2.1 Sharing among labmates. Many CloudLab users belong to research labs where multiple members have CloudLab accounts. We observed that lab members often shared the knowledge and resources they had developed with their less experienced peers. For example, labmates shared tutorials and the scripts they had written to install dependencies. It was also common within a lab to reuse any CloudLab profiles they had developed themselves. Such resource sharing saved time for new learners.

However, we also saw that the use of CloudLab projects could create competition within the lab for resources like time. When multiple lab members belong to the same CloudLab project (a common occurrence), a reservation made by one member is also available for use by another. It is left up to the collaborators or PI to decide who has access to the reserved nodes and when. One participant, P3, a professor who supervises several students, uses their authority to determine how CloudLab time is allocated:

> *"I tell them, 'Hey, if you're not using, I'm going to. I'm going to delete your cluster and I'm going to ask for those nodes.' So, then they have no choice but to say yes."*

5.2.2   Sharing time. During our interviews and observation, participants showed that they understood CloudLab nodes to be rivalrous resources, unsharable by two users at a given time. The competition among lab members for CloudLab time demonstrates this, but we also saw that because they understood this rivalry some users were altruistically motivated to share the nodes available to them.

Multiple participants told us that they would end their reservations when they had completed data collection so that others could use the nodes. For instance, P2 shared with us:

> *"If I feel pretty confident that I'm really done then I'll just terminate the experiment...I usually prefer to terminate it and give the resources back in case somebody else needs them, rather than just hold on to them arbitrarily for, you know, ten hours."*

P12 described doing the same thing in the "hope that...it will become available for...another user." P4 also described engaging this altruistic practice "as a courtesy to others." However, P4 further mentioned an important caveat regarding sharing nodes—they shared nodes with others unless a publication deadline was approaching:

> *"...Once we are sure that we are done with our use we usually terminate that reservation...As an avid user of CloudLab, I know how difficult sometimes it's- it is to get those nodes. . . As a courtesy for other users, we just try to. . . delete the reservation once it's done...We know when the paper deadline we planned to would be, so we try to keep it during that time and then try to have that node until the end...at least, I mean, unless the paper is submitted, we know that we might need it in case."*

Beyond just courtesy, we saw that policies may be in place to require the timely return of CloudLab nodes. For instance, P10 explained how they enforce the practice of releasing nodes when the students in their course are done using them:

> *"I tell it to them in my instructions, you know. Every experiment ends with, 'Make sure you delete your resources'. The last question on the lab assignment is 'upload a screenshot showing that you deleted your resources'."*

Although we were surprised by the prevalence of this altruistic sharing of CloudLab time, we also heard interviewees repeat P4's anxiety about needing nodes. P12, for instance, explained that they keep extra resources on hand temporarily to avoid the ramifications of unexpected failures and wasted time:

> *"I'm making sure I reserve more nodes than needed. And then after I make sure that connectivity-wise the number of nodes I want are fine, I'll just delete the rest to release them. In this case, I avoid this problem."*

5.2.3   Coordinative tools. Participants in our study had to align their use of the cloud computing system to fit with other users' reservations already in place. We observed that some features of CloudLab such as the resource availability graphs (see Figure 2), table views of experiments, and
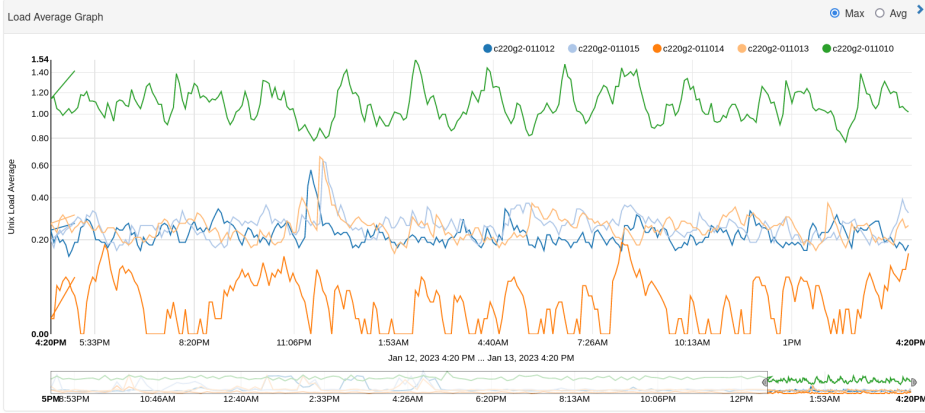
(a) Five nodes' load average over time. A load average of 0 indicates an idle machine. As the load average increases, this indicates more processes running or queued up.

(b) A table view of ongoing experiments in a shared project

Fig. 3. Additional visualizations for coordinating time. Panel A shows how much computational power is used over time; a load of 0 indicates a node is idle and not in use. Panel B is a table CloudLab users can leverage to see how many active experiments are ongoing in the project they share with peers.

other visualizations of computational work done during experiments (i.e., node load average, see Figure 3a) served as coordinative tools for managing time.

Resource availability graphs were a standard reference point for CloudLab users. Although these graphs did not instruct researchers on how to use the platform, they provided information that was nevertheless critical to experimentation. P7, for example, relied on the visualizations to know when they could expect to make use of CloudLab nodes:

> *"One thing I find really useful is the resource availability tab. So this, I think, especially during the times when the semesters are going on, it's very hectic. There's a lot of people I think using it....So, this particular graph, along with the time when they will be available, helps me plan my future experiments."*

The resource availability graphs indicate which nodes with which hardware are available to be used or reserved at a given time. This information allowed users to estimate not just the speed of their work but also which work would be accomplished. P5, for instance, used the resource availability graphs to determine how they would execute their study:

> *Interviewer: "So, how do you decide which [experiment setup] profile you would be using?"*
> *P5: "Based on availability."*

Depending on the hardware shown to be available at the time, P5 would construct different clouds.

Other participants also shared how important the resource availability graph is for coordinating their research efforts and estimating their time to completion. However, this sometimes led to frustration because pending reservations and future reservation extensions could not be included in the visualization. User like P9 felt their ability to plan, budget, and anticipate their time was hampered by this:

> *"... if the availability graph actually showed included [future] reservations, I think I would have adjusted my own expectations to know how fast I would be able to run the experiments and how fast I can generate the results."*

Despite any shortcomings, the resource availability graphs were key tools to help users independently coordinate their time on CloudLab with other users. When working on a project where reservations are shared among members, other visualizations were also useful for managing issues of time. P3, for instance, leveraged information provided by the platform to know who among their students was "not using" their CloudLab time. A table view of all ongoing experiments and line graphs of each experiment's computational work (i.e., load average) both provide records of CloudLab time used (see Figure 3b). P3 relied on the information provided by these tools:

> *"So, if I see that the load average is zero for like, several days, then I tell them, 'Hey, you're not using it. I'm gonna use it'."*

5.2.4 Artifacts for the future. While collaborators could synchronously discuss the particulars of how to run an experiment, some of our participants also helped future researchers understand and reproduce their work by sharing well documented research artifacts like scripts. As this quote from P13 demonstrates, one common method for sharing such artifacts was using a public Github repository:

> *"I guess it depends on the venue but the basic thing is to put everything online in the Git repo. So now people can find it."*

Github was used by nearly all of our participants but local practices for informing future readers were evident as well. P15, for instance, described their lab's routine of sharing experiment documentation on their lab website:

> *"We have this blog post on our lab's website, which, basically, we try to make everything reproducible and open source. So for this one, we were preparing these instructions… When someone looks at our experiment, they should be able to run the basic commands and do it."*

P15's outlook on what documentation and artifact sharing should accomplish was common among our participants; they held that artifacts should be useful and intelligible to future viewers. However, we observed different preferences for when these artifacts or materials were created for sharing. Some participants said that they do their documentation at the end, right before publication. Others explained that internal documentation created during their study is later tidied up for publication. For example, P6 told us:

> *"So from the very beginning, we tried to make- keep guides and READMEs ready, although they may not be of very high quality… So for the best interest of the paper, we just polished the repository a little bit, refactored a little bit, added some comments, and send the link."*

Notably, while research artifacts are by definition relics of past work, some participants expressed that sharing them could affect future rewards. The timing of when an artifact is shared matters. P12 told us:

> *"You do your best to have everything public. Other times because [it's] still work in progress or it may lead to a different project you don't want to make the work… public yet."*

They elaborated:

> "Sometimes people may just want to get some information from you and use it for their own benefit....It may be the case that they published first before you, let's say, and then you don't get credit for your effort."

Thus, we found that while some researchers may be keen to share their work artifacts with others, concerns about receiving proper credit for their work remain.

6 DISCUSSION

Through semi-structured interviews and observation, we found that CloudLab users try to optimize their use of time when they engage with the system. Learning from peers, mentors, and trial and error, users develop strategies to gain and protect CloudLab time—possibly wresting it from colleagues. However, we also observed that CloudLab users like P2 perceived the value of CloudLab time to others' and altruistically ceded it when possible, as demonstrated in Section 5.2.2.

This generosity was unanticipated, though it is a behavior to cultivate. CloudLab developers seek to balance node use across time, reducing periods of scarcity to ensure that users can reserve time on the platform whenever needed [12]. Thus, recognizing this altruistic behavior, we hope to encourage it through design to find the balance CloudLab developers aspire for. Lindley [19] writes, "Designing for an alternative temporal experience means understanding the ways in which multiple temporalities intersect." In this section, we make sense of the temporalities observed in the present research by using the language of prior CSCW authors. We present the rhythms of CloudLab time and academic deadlines as intertwined, positing that the urgency for action affects how users relate to CloudLab time and their willingness to share it. We then further hypothesize that visualizations like the resource availability graphs support the anticipation work [30] involved in aligning disparate rhythms. In light of these insights, we propose several design interventions to cultivate an "alternative temporal experience" [19] where CloudLab time is shared among users with greater facility.

6.1 Aligning Rhythms

As described in our results, we observed users working to conduct experiments, produce publications, and manage their time. These efforts can be understood as anticipation work [30]. Anticipation work is an attempt to align present efforts with a desired future. In this case, CloudLab users took action to progress toward their personal and communal goals. These actions can be organized into Jackson et al.'s [16] taxonomy of collaborative rhythms, allowing us to describe their complementary and conflicting nature at an abstract level.

One salient rhythm in our data is the organizational rhythm [16] brought on by publications and conference deadlines. Our participants described engaging in new patterns of activity as deadlines approached. For example, in anticipation of sharing a research artifact or publishing a paper, CloudLab users validate their findings through replication and tidy up their scripts and documentation. The routine adoption of such practices in advance of a deadline reveals a rhythm.

Like Chen et al.'s [8] "machine time", the infrastructural rhythm of CloudLab time is dictated by the ebb and flow of free nodes. As the platform developers bring machines online and users request their allocation, node availability rises and falls. Duplyakin et al. [12] saw that CloudLab traffic increases when conference and semester deadlines loom; the experiences reported by participants in our study further attest to the salience of this rhythm.

While we can describe these rhythms separately, in practice CloudLab users' organizational and infrastructural rhythms are entangled; they must produce papers on time with the available facilities. Thus, we saw users engage in anticipation work to ensure alignment between the timing

of their experiments and CloudLab node availability. Users adopted strategies akin to "scheduling defensively" [23], attempting to gather enough CloudLab time that an unanticipated loss would not be catastrophic. Participants reported using these strategies when working under the pressure of a deadline, indicating that the closeness of a temporal horizon [26] might prompt them to relate differently to infrastructural rhythms.

Indeed, quotes like that from P4 above suggest that the value of CloudLab time to an individual is variable. Close horizons indicating the scarcity of time may increase its value. This would explain why we see scenarios like P9 learning to be a "resource hawk," collecting more CloudLab time to avoid missing publication deadlines (see Section 5.1.3). The altruistic behavior we have observed can also be understood as an example of this pattern. CloudLab users who have flexible and distant horizons have little urgency to their work [26] and can, therefore, surrender their low-value CloudLab time to others who would value it more. Instead of engaging in anticipation work to protect their personal CloudLab time they try to conjure a future where CloudLab time is collectively optimized.

It is this collective optimization that we hope to nurture through design. We next posit that visualizations played an important role in cultivating altruistic behaviors and supporting anticipation work on CloudLab before turning to the design implications of our results and discussion.

6.2 Visualizing Resource Availability

We observed that CloudLab users heavily relied on the resource availability graphs (see Figure 2) to support their planning and, therefore, anticipation work. Participants referred to these graphs regularly to know which nodes would be free for use.

In light of our literature review and the findings presented above, we hypothesize that the routine use of resource availability graphs fostered a collective understanding of CloudLab time and its rivalrous nature. A shared or "collective" [19] understanding of time may be developed through visualizations that simplify mental processes and provide a standard reference to organize action around [3, 5, 16, 30]. Visualizations thus promote the awareness that CSCW authors have shown is critical to coordination [11]. The resource availability graphs appear to fill this role by visualizing how others' use of CloudLab constrains the instantiation of new experiments. P5, as previously described, chose which experiment profile to use based on how many of which machines were available at the time. In this way, the resource availability graphs allow individuals to align their own rhythms with the collective's, possibly optimizing for mutual benefit.

Individuals may align themselves with the infrastructural rhythm set by all CloudLab users, but, as noted in our results, this alignment may also occur at a more local level within labs and classrooms. For example, within labs, we saw that colleagues leveraged visualizations other than the resource availability graphs to draw conclusions about who needed CloudLab time most. P3 relied on information like that shown in Figure 3 of Section 5.2.3 to align their students' work rhythms for maximum productivity within the lab, determining who would make the best use of CloudLab time. These additional visualizations supported anticipation work at a more local level than the resource availability graphs.

6.3 Designing for an Alternative Temporal Experience

While the resource availability graphs appear to be useful tools for planning, our findings suggest two additional opportunities to further develop the altruistic behavior we witnessed and otherwise support the anticipation work of coordinating CloudLab time.

6.3.1 Reconciling organizational and infrastructural rhythms. First, we can support the anticipation work that reconciles organizational rhythms like publication deadlines and semester schedules

with infrastructural rhythms. Participants in our study leaned heavily on the resource availability graphs to align their need for CloudLab time with the reservations and ongoing experiments already in place. In light of our hypothesis that these graphs afforded a collective sense of CloudLab time, we could maximize this shared understanding through new visualizations and supplements to the existing graphs. Specifically, these new visualizations would communicate not just the infrastructural rhythm of node availability, but also how it intersects with organizational rhythms.

With such additional shared resources, CloudLab users could plan more effectively. For example, the resource availability graph could indicate expected periods of high demand, signaling to users that they should reserve nodes early. In this case, the week in advance of a popular conference's deadline might be highlighted in red, indicating the high likelihood of resource scarcity. Another similar design intervention could involve collecting data from users making reservations, asking them what deadline they are working toward. While responses would not affect the decision to approve their reservation request, the data could be made visible to other CloudLab users to indicate the sense of urgency their peers have. A banner reading "13% of CloudLab users are working toward a deadline at midnight tonight" might prompt a user with unneeded nodes to cede them for others' use. Our strategy with these interventions, like Begole et al. [5], Fisher and Dourish [13], and Morrison-Smith et al.'s [21], would be to increase awareness of the multitude of peers' work rhythms, affording better coordination. With this strategy in place, users would be able to more accurately compare their own need for CloudLab time to others', hopefully yielding altruistic behavior.

6.3.2 Using trajectories to anticipate. Second, we observed that anticipation work occurred to align individuals with the rhythms of both the collective CloudLab user base and their local lab group. When members of a lab group were part of the same CloudLab project, they shared access to the same reservations and thus had to coordinate how they spent CloudLab time. As specified above, this anticipation work involved visualizations other than the resource availability graphs like the load average graphs. It also sometimes led to competition among colleagues. "The fastest person wins," P9 told us. An additional design implication of the present work is, therefore, to further support anticipation work at the project level, ideally reducing competition through facilitated planning.

This support could help colleagues establish temporal trajectories like those used by the SICU staff in Reddy et al.'s [26] ethnography. While Reddy et al. [26] use the term temporal trajectory to refer specifically to a patient's recovery status, we employ the term here more broadly. A temporal trajectory, in our sense, is the status of an individual as inferred by others. With a clear sense of their colleagues' experimental temporal trajectories, other project members may be better able to anticipate how their desired infrastructural rhythms interact. If a trajectory is known to be behind schedule, for instance, this may signal to colleagues that they should delay their own non-urgent work, keeping CloudLab time available for their lagging peer.

In practice, supporting anticipation work by publicizing temporal trajectories could take many forms. One option is to simply visualize resource availability at the project level, drawing particular attention to colleague's work rhythms as opposed to all CloudLab users'. Also, similar to the above-mentioned options for publicizing deadlines, the approach illustrated in Figure 4 could be used to indicate project members' deadlines and progress toward them. The knowledge that a labmate is troubleshooting and aiming for a deadline two months from now would establish a very different temporal trajectory from the knowledge that they are replicating their findings for a near-term deadline. While this strategy would likely not scale well, it could incite more altruistic behavior among labmates and collaborators.
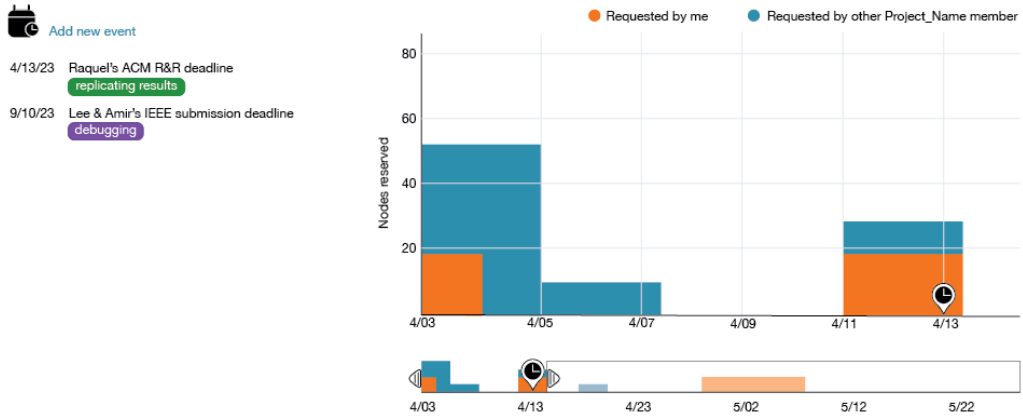
Fig. 4. A proposed visualization to add to CloudLab. This visualization displays nodes reserved by the user (in orange) and their group members (in blue) over time. A calendar feature allows users to share important deadlines and tag those deadlines with their current status (e.g., debugging). We hypothesize this chart will raise awareness of project members' deadlines and their progress toward them, creating a collective understanding of time and enabling anticipation work.

Interestingly, while we expect that raising awareness of project members' temporal trajectories would be useful for coordination, our data also suggest that such information could introduce new social complications. As many authors have recognized, allocating time is an exercise of power and a judgment on the value of an activity [16, 20, 29]. P3 showed us that PIs may use their power to re-allocate CloudLab time among subordinates based on their evaluation of how well that time is being spent (see Section 5.2.1). Thus, while design interventions like that shown in Figure 4 are intended to yield a more informed approach than P9's "fastest person wins" strategy, they may also increase the likelihood of disputes over authority and research value. Prior authors have raised concerns about issues of privacy when visualizing automatically collected activity traces [13]; it is possible that establishing a temporal trajectory by *manually* tagging deadlines would mitigate concerns of being "outed."

6.4 Future Work and Implications for Other Systems

In future work, we plan to validate the ideas put forth in our discussion. Following the example of prior literature (e.g., [5, 13, 21]), we can augment the insights from our qualitative data with those derived from quantifiable activity traces. With such traces, we will be able to evaluate the efficacy of our proposed interventions like the banner showing the urgency of users' work. For example, we could compare the frequency with which reservations are ended early (an altruistic behavior) before and after the banner is introduced.

The empirical evaluation of methods to support anticipation work has value beyond our own research setting. The concerns with time evident in our data are also visible in other rivalrous cyberinfrastructure systems in science. Chen et al. [8], for example, described their study participants as having similar goals to the CloudLab developers: "The HPC center staff juggle complex temporal rhythms, attempting to meet scientists' needs while maintaining high system utilization." Further parallels can be made between the present study and Chen et al.'s [8]. For instance, system users in both cases were troubled by what they viewed as wasted time spent on moving data between

storage systems or setting up environments. Additionally, the timing of publications, conferences, and courses are relevant to the use of any scholarly infrastructure—not just CloudLab.

Therefore, while our case is unique, the insights we have developed are applicable to other scientific systems. We have proposed that temporal trajectories [26] have utility beyond their original medical context and can be employed as a useful cue for anticipation work in other cooperative settings. Other CSCW authors may find this broader interpretation of the concept useful as well. Furthermore, we have recognized the entangled nature of publications and academic calendars with infrastructural rhythms, positing that anticipation work can be facilitated by visualizing the relationships between those rhythms. Other scientific cyberinfrastructure systems might also explore how the timing and activities of their users are structured by the rhythms of academia. They can use design as an opportunity to lean into the anticipation work their users already partake in. A conscientious approach is necessary, however, as a person's temporal trajectory could be used against them if made public.

Finally, we encourage other researchers and cyberinfrastructure developers to establish partnerships such as the one we have with CloudLab. While other studies have considered the relationship between time and use of scholarly cyberinfrastructure systems (e.g., [3, 5, 8, 10, 16, 27, 29]), this work (like ours here) is rarely hypothesis driven (an exception is [21]). We look forward to breaking this mold in future by evaluating our proposed interventions, an effort that will be greatly facilitated by our partnership. The research process from recruitment to data collection will benefit from our collaboration with CloudLab developers. Unlike us, these collaborators have ready access to users and the ability to make interface changes. In turn, the platform will benefit from our empirical findings and the opportunity to offload user research onto experienced scholars. Our collaboration is funded by the National Science Foundation, and is predicated on the idea that our work will enhance the CloudLab user experience. Partnerships like this can both improve scholarly infrastructure as well as our ability to test CSCW theory.

7 CONCLUSION

Scientific researchers demonstrate altruistic behaviors when performing research with a free-of-cost but rivalrous scientific software or platform. This paper presented the qualitative study of such a platform for cloud computing research, focusing on how its users established different rhythms of activity structured by the influence of the academic calendar and publication priorities. We observed the importance of time as a resource and seek to further cultivate the altruistic time sharing practices that some of our participants engaged in. To that end and in light of prior literature, we have proposed concrete opportunities for design interventions. Our strategy across all possible interventions is to increase users' awareness of the rhythms affecting their peers' platform use, allowing coordination based not just on knowledge of CloudLab reservations but also on users' progress toward deadlines. The implications of this work inform the design of other similar cyberinfrastructure systems in science where users independently coordinate the use of resources.

REFERENCES

[1] 2020. Artifact Review and Badging - Current. https://www.acm.org/publications/policies/artifact-review-and-badging-current

[2] Vincanne Adams, Michelle Murphy, and Adele E Clarke. 2009. Anticipation: Technoscience, life, affect, temporality. *Subjectivity* 28, 1 (Sept. 2009), 246–265. https://doi.org/10.1057/sub.2009.18

[3] Cecilia R. Aragon, Sarah S. Poon, Gregory S. Aldering, Rollin C. Thomas, and Robert Quimby. 2008. Using visual analytics to maintain situation awareness in astrophysics. In *2008 IEEE Symposium on Visual Analytics Science and Technology*. 27–34. https://doi.org/10.1109/VAST.2008.4677353

[4] M L Badger, T Grance, R Patt-Corner, and J Voas. 2012. *Cloud computing synopsis and recommendations.* Technical Report NIST SP 800-146. National Institute of Standards and Technology, Gaithersburg, MD. NIST SP 800–146 pages. doi.org/10.6028/NIST.SP.800-146

[5] James "Bo" Begole, John C Tang, Randall B Smith, and Nicole Yankelovich. 2002. Work Rhythms: Analyzing Visualizations of Awareness Histories of Distributed Groups. In *Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work (CSCW '02)*. Association for Computing Machinery, New Orleans, Louisiana, USA, 334–343. https://doi.org/10.1145/587078.587125

[6] Matthew J. Bietz, Eric P. S. Baumer, and Charlotte P. Lee. 2010. Synergizing in Cyberinfrastructure Development. In *Computer Supported Cooperative Work (CSCW)*, Vol. 19. 245–281. https://doi.org/10.1007/s10606-010-9114-y

[7] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (Jan. 2006), 77–101. https://doi.org/10.1191/1478088706qp063oa

[8] Nan-Chen Chen, Sarah Poon, Lavanya Ramakrishnan, and Cecilia R. Aragon. 2016. Considering Time in Designing Large-Scale Systems for Scientific Computing. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing (CSCW '16)*. Association for Computing Machinery, San Francisco California USA, 1535–1547. https://doi.org/10.1145/2818048.2819988

[9] Adele E Clarke. 2016. Anticipation Work: Abduction, Simplification, Hope. In *Boundary Objects and Beyond*. MIT Press, 85–119.

[10] Alessandro Delfanti. 2016. Beams of particles and papers: How digital preprint archives shape authorship and credit. *Social Studies of Science* 46, 4 (Aug. 2016), 629–645. https://doi.org/10.1177/0306312716659373

[11] Paul Dourish and Victoria Bellotti. 1992. Awareness and coordination in shared workspaces. In *Proceedings of the 1992 ACM Conference on Computer-Supported Cooperative Work (CSCW '92)*. Association for Computing Machinery, Toronto, Ontario, Canada, 107–114. https://doi.org/10.1145/143457.143468

[12] Dmitry Duplyakin, Robert Ricci, Aleksander Maricq, Gary Wong, Jonathon Duerig, Eric Eide, Leigh Stoller, Mike Hibler, David Johnson, Kirk Webb, Aditya Akella, Kuangching Wang, Glenn Ricart, Larry Landweber, Chip Elliott, Michael Zink, Emmanuel Cecchet, Snigdhaswin Kar, and Prabodh Mishra. 2019. The Design and Operation of CloudLab. In *Proceedings of the 2019 USENIX Conference on Usenix Annual Technical Conference.*

[13] Danyel Fisher and Paul Dourish. 2004. Social and temporal structures in everyday collaboration. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '04)*. Association for Computing Machinery, Vienna, Austria, 551–558. https://doi.org/10.1145/985692.985762

[14] Anthony Giddens. 1986. *The Constitution of Society: Outline of the Theory of Structuration.* University of California Press.

[15] James Howison and James D. Herbsleb. 2013. Incentives and integration in scientific software production. In *Proceedings of the 2013 Conference on Computer Supported Cooperative Work (CSCW '13)*. Association for Computing Machinery, San Antonio, Texas, USA, 459–470. https://doi.org/10.1145/2441776.2441828

[16] Steven J. Jackson, David Ribes, Ayse Buyuktur, and Geoffrey C. Bowker. 2011. Collaborative rhythm: temporal dissonance and alignment in collaborative scientific work. In *Proceedings of the ACM 2011 Conference on Computer Supported Cooperative Work (CSCW '11)*. Association for Computing Machinery, Hangzhou, China, 245–254. https://doi.org/10.1145/1958824.1958861

[17] Marina Jirotka, Charlotte P. Lee, and Gary M. Olson. 2013. Supporting Scientific Collaboration: Methods, Tools and Concepts. *Computer Supported Cooperative Work (CSCW)* 22 (Aug. 2013), 667–715. https://doi.org/10.1007/s10606-012-9184-0

[18] Leslie Lamport. 1978. Time, clocks, and the ordering of events in a distributed system. *Commun. ACM* 21, 7 (July 1978), 558–565. https://doi.org/10.1145/359545.359563

[19] Siân E. Lindley. 2015. Making Time. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing (CSCW '15)*. Association for Computing Machinery, Vancouver, BC, Canada, 1442–1452. https://doi.org/10.1145/2675133.2675157

[20] Melissa Mazmanian, Ingrid Erickson, and Ellie Harmon. 2015. Circumscribed Time and Porous Time: Logics as a Way of Studying Temporality. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing (CSCW '15)*. Association for Computing Machinery, Vancouver, BC, Canada, 1453–1464.

https://doi.org/10.1145/2675133.2675231

[21] Sarah Morrison-Smith, Lydia B Chilton, and Jaime Ruiz. 2021. AmbiTeam: Providing Team Awareness Through Ambient Displays. In *Proceedings of the 2021 International Conference on Graphics Interfaces*. Association for Computing Machinery. https://sarahmorrisonsmith.com/wp-content/uploads/2022/01/AmbiTeam-Providing-Team-Awareness-Through-Ambient-Displays.pdf

[22] Wanda J. Orlikowski and JoAnne Yates. 2002. It's about Time: Temporal Structuring in Organizations. *Organization Science* 13, 6 (2002), 684–700. https://doi.org/10.1287/orsc.13.6.684.501

[23] Leysia Palen. 1999. Social, Individual & Technological Issues for Groupware Calendar Systems. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '99)*. Association for Computing Machinery, Pittsburgh, PA, USA, 17–24. https://doi.org/10.1145/302979.302982

[24] Elena Parmiggiani, Eric Monteiro, and Vidar Hepsø. 2015. The Digital Coral: Infrastructuring Environmental Monitoring. *Computer Supported Cooperative Work (CSCW)* 24, 5 (Oct. 2015), 423–460. https://doi.org/10.1007/s10606-015-9233-6

[25] Maria Puig de la Bellacasa. 2015. Making time for soil: Technoscientific futurity and the pace of care. *Social Studies of Science* 45, 5 (Oct. 2015), 691–716. https://doi.org/10.1177/0306312715599851

[26] Madhu C. Reddy, Paul Dourish, and Wanda Pratt. 2006. Temporality in Medical Work: Time also Matters. *Computer Supported Cooperative Work (CSCW)* 15, 1 (Feb. 2006), 29–53. https://doi.org/10.1007/s10606-005-9010-z

[27] David Ribes and Thomas A. Finholt. 2007. Planning infrastructure for the long-term: Learning from cases in the natural sciences. In *Proceedings of the Third International Conference on e-Social Science*. Ann Arbor, MI. http://interoperability.ucsd.edu/docs/RibesFinholt07_LearningFromEScience.pdf

[28] Susan Leigh Star and Karen Ruhleder. 1996. Steps Toward an Ecology of Infrastructure: Design and Access for Large Information Spaces. *Information Systems Research* 7, 1 (1996), 111–134.

[29] Stephanie B. Steinhardt and Steven J. Jackson. 2014. Reconciling rhythms: plans and temporal alignment in collaborative scientific work. In *Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing (CSCW '14)*. Association for Computing Machinery, Baltimore, Maryland, USA, 134–145. https://doi.org/10.1145/2531602.2531736

[30] Stephanie B. Steinhardt and Steven J. Jackson. 2015. Anticipation Work: Cultivating Vision in Collective Practice. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing (CSCW '15)*. Association for Computing Machinery, Vancouver, BC, Canada, 443–453. https://doi.org/10.1145/2675133.2675298

[31] Richard H Thaler and Cass R Sunstein. 2009. *Nudge: Improving Decisions About Health, Wealth, and Happiness*. Penguin Books.

[32] Erik H. Trainer, Chalalai Chaihirunkarn, Arun Kalyanasundaram, and James D. Herbsleb. 2015. From Personal Tool to Community Resource: What's the Extra Work and Who Will Do It?. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing (CSCW '15)*. Association for Computing Machinery, 417–430. https://doi.org/10.1145/2675133.2675172

[33] Judy Wajcman. 2019. The Digital Architecture of Time Management. *Science, Technology, & Human Values* 44, 2 (March 2019), 315–337. https://doi.org/10.1177/0162243918795041