Collaborative Rhythm: Temporal Dissonance and Alignment in Collaborative Scientific Work

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ABSTRACT
CSCW studies of large-scale distributed practice in the sciences and elsewhere have taught us important things about space and place as props and barriers to distributed collective action, but they have had relatively less to say about time. This paper develops a heuristic of collaborative rhythms and points to the work of temporal alignment as a neglected but crucial element underpinning distributed collective practice in the sciences (and other spheres of collective activity). Specifically, we argue that joint scientific work is organized around four separate registers, or 'rhythms' – organizational, infrastructural, biographical, and phenomenal – and that efforts to align such rhythms constitute an important and under-recognized aspect of collaborative work. The ideas and examples are drawn from our own field studies around IT infrastructure and collaborative practice across a range of scientific fields.

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Human Factors, Management, Theory.

INTRODUCTION
Questions of space, place and distance have long been central to CSCW studies of distributed collective work. Much of this research has focused on the subtle assists that shared place provides in the structuring of collaborative activity. For example, researchers have studied contextual awareness [e.g. 17, 38], spontaneous informal communication [e.g. 19, 43], and building effective common ground or mutual knowledge [e.g. 8, 9]. Other scholars have explored spatial themes in studies of real or virtual collocation [e.g. 30, 40], media spaces [e.g. 15], and shared workspaces [e.g. 11]. Inspired by these insights, much work coming out of the design wings of the CSCW and HCI communities has sought to recreate the hidden affordances of place in distributed technical and organizational forms, seeking to restore through design the ever-elusive experience of "being there" [21]. The net result of this work, in broad keeping with the 'spatial turn' in the social sciences at large, is the widely accepted understanding that in the practice of collaborative activity, "distance matters" [33].

The corollary to this finding – that "time matters" – has been less well explored. The present paper addresses this gap. We begin by reviewing current work around time and collaboration in CSCW, including work from the organizational and social sciences at large that we believe holds important lessons for CSCW scholarship. Next, we develop a heuristic of rhythms in collaborative work, drawing on our own studies of collaborative work in ecology and other fields of science. Specifically, we argue that joint scientific work is organized around four separate and potentially dissonant temporal registers, or 'rhythms': organizational, infrastructural, biographical, and phenomenal – and that efforts to align such rhythms constitute an important and under-recognized aspect of scientific work. The next section demonstrates these principles empirically, detailing cases of temporal dissonance and alignment from the very different worlds of space exploration and ecology. Finally, we conclude with implications for CSCW research, including challenges confronting the field as it seeks to develop more robust and 'timely' forms of scholarship.

TIME AND COLLABORATION
CSCW has paid consistent attention to the variable effects of distance and location on collaborative form and practice, but has had relatively less to say about time. At a practical level, CSCW researchers have explored the challenges imposed by collaborative work among team members working in different time zones, usually inter-continental work teams of transnational corporations [e.g. 41, 33]. CSCW scholars have also studied the variable forms and patterns of synchronous and asynchronous communication among team members, and aspects of synchronicity have been discussed in the context of specific affordances of different communication and information technologies that support collaborative activities [e.g.6, 7, 18]. But most such studies have treated

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temporal issues in relatively narrow scope, focusing on one facet without paying attention to the many different and fluctuating rhythms present in collaborative work. Efforts to disentangle or connect across the variable effects of space and time in given collaborations are rarer still.

An important body of time-related work in CSCW relates to forms of temporality associated with the design and use of specific collaborative artifacts. Palen [35] and Lee [27] draw attention to the multifarious nature of "calendar work," noting the use of calendars for temporal orientation, scheduling, tracking, reminding, recording/archiving, and retrieval and recall. Tyler and Tang [42] study forms of temporality associated with email use, including actors' interpretations and management of the subtle social cues embedded in response times. Fisher and Dourish [14] and Begole et al. [4] show how traces of electronic activity (email traffic, keyboard and mouse activity, calendar data, etc.) can be mined to identify temporal patterns and build contextualized awareness tools that support collaboration.

Other CSCW scholars have approached questions of temporality in specific work contexts, often centered on mobile and time-critical settings. Nilsson and Hertzum's [32] work on home care in Denmark documents the role of individual, collective, and social rhythms in constituting overall patterns of home-care activity. Landgren's [26] work on Swedish fire and rescue crews examines how rhythms emanating from rapid mobilization, emergency intervention, and situational adjustment shape patterns of collaboration and accountability under conditions of time-critical verbal communication. Studies by Bardram [3], Egger and Wagner [13], and Reddy et al. [36] have analyzed the temporal organization of work in surgical settings, arguing the need to incorporate time-sensitive notions of flow and awareness into the study and design of medical information spaces.

An important strain of CSCW work around time has drawn on ethnomethodological and/or pragmatist roots. For example, Reddy et al.'s [36] study of temporal 'trajectories,' 'rhythms,' and 'horizons,' in a surgical intensive care unit approaches "the production and negotiation of temporal order… as a practical accomplishment of social actors" (p. 31). This work bears important relation to our own, though we choose not to deploy the information-seeking framework at the heart of that study, and deploy rhythm in a more overarching sense (gathering, rather than separating out, phenomena described by Reddy et. al. under 'trajectories' and 'horizons.') Other work has built from more cognitivist or psychological foundations: for example, Mainemelis' [29] argument that individual experiences of time (and variations between them) emerge from the ability of consciousness to separate stability from change (p. 549). Running through this literature are two central fault lines. The first concerns the relationship between individual and collective forms of temporality. As Mainemelis suggests, time and its passage may be posited as both or either a highly individual phenomenon, rooted in individual experiences, perceptions, and expectations, and a largely collectivized phenomenon, with 'structural' properties determined at the group, institutional, and wider sociocultural levels. There is a clear tension in these accounts, which may be regarded either as a limit in our thinking, or more charitably a reflection of the constitutive tension, or tug and pull, endemic to human experience of time itself. Our move to rhythm as a category of analysis is meant to sidestep this problem, or at the very least avoid privileging one side of this divide over the other. We return to this question in the discussion section that follows.

The second axis is the hoary problem of subjectivity and objectivity. Objectivist notions of time, for which the ticking clock serves as a primary metaphor, depict a forward-moving linear continuum infinitely divisible into homogeneous, precise, deterministic, and measurable units [1, 2]. Objective time is depersonalized, abstract, and in some sense given, confronting human actors from the outside of and beyond all individual or collective frames of meaning and interpretation (even where the latter play some role in conditioning personal or group experiences of time). In contrast, subjectivist notions emphasize the individual and social construction of time, regarding time as the "product of the norms, beliefs, and customs of individuals and groups" [34; p.685] – for example, the 9-to-5 work day once common in many Western societies. Socially, time is a humanly suffused construct that can vary significantly between eras and cultures as well as within and between individuals.

Notable attempts to overcome this dichotomy can be found in the organizational science literature in work by Orlikowski and Yates [34] who make forceful arguments around the 'enacted' character of time and its relationship with organizational form and practice. Arguing that "difficulties arise when these positions are treated not as conceptual tools but as inherent properties of time" (p.686), the authors bridge the objective/subjective divide through the notion of temporal structuring, derived from a focus on human practices as opposed to an external force or subjective construction. In this view, actors produce and reproduce a variety of temporal structures through their everyday actions, and in turn these structures shape the temporal rhythm and form of ongoing practices. Hence, people establish and reinforce temporal structures as legitimate and useful organizing structures for their community, and such legitimized temporal structures –

while always potentially changeable – become taken for granted, serving as powerful templates for rhythms of social action [34; p. 685]. For Orlikowski and Yates, temporal structuring provides a vehicle for talking across a series of entrenched divides – universal/particular, linear/cyclical, natural/social, open-ended vs. closed – that have hobbled social scientific research on time to date. Another advantage in this perspective comes with the seriousness it accords individual and group-level choices in altering the temporal forces that would otherwise appear to impinge on them very much from the outside; from this perspective, "people are purposive, knowledgeable, adaptive, and inventive actors who, while they are shaped by established temporal structures, can also choose, whether explicitly or implicitly, to (re)shape those temporal structures to accomplish their situated and dynamic ends" (p. 688).

Like Orlikowski and Yates, we seek to overturn the conceptual divide between time as an intractable objective beat or a fully malleable social syncopation. We also wish to account for the role of non-human forces and actors in the shaping of time in ways that do not leave aside the important insights gained from 'social' perspectives on time and its organization. Rhythm (or more properly rhythms) is our vehicle for getting there. More specific and multiple than objectivist positions or the flat category of temporality would allow, more given and external to action than subjectivist positions might acknowledge, rhythms constitute a central part in the ongoing shape and shaping of collective action, in the sciences as elsewhere.

Our work contributes to existing time studies in CSCW in three ways. First, it extends temporal analysis to a form or category of CSCW work – namely, spatially and temporally distributed scientific collaboration – that has yet to occupy the central attention of the field. Second, it identifies four central forms or kinds of collaborative rhythm – organizational, infrastructural, biographical, and phenomenal – that shape temporal experience and practice in collaborative scientific settings. And third, it points to under-recognized forms of alignment work needed to bring the otherwise disparate rhythms of scientific life into some form of workable coherence.

MAPPING COLLABORATIVE RHYTHMS

As the above discussion has tried to make clear, all forms of distributed collective activity are subject to rhythm. Things emerge, grow, evolve, and give way to new phenomena according to distinctive patterns. Changes in the built environment follow not only particular directions (the lessons of path dependency [10] and momentum [22]) but also distinctive temporalities of change. Groups and organizations grow, change, and evolve according to temporal patterns all their own. And humans themselves are rhythmic creatures, subject to temporal patterns ranging from the diurnal to the biological cycles of birth, growth, and death. The layering or interweaving of these rhythms has deep and constitutive effects on distributed collective activity in all its forms. Our argument here is for the endogeneity of rhythm(s) and all forms of collective action; i.e., that distributed collective practices not only have rhythms, but in some fundamental sense are rhythms. Rhythms constitute distributed collective practice, and vice versa.

The following section considers such effects in the worlds of scientific collaboration we study. We argue that successful scientific collaborations must seek to accommodate and align four separate kinds or modalities of time, each of which shape and structure the rhythms of collaborative work in specific and often challenging ways. The first two of these – organizational and infrastructural rhythms – align with long-standing CSCW concerns around organizational practice and system/artifact design (though these discussions have not always fore-grounded specifically temporal dimensions). The second two – biographical and phenomenal rhythms – have tended to escape notice and theorizing within CSCW and the social sciences, with negative consequences for both understanding and design.

Organizational Rhythms

Patterns of collaboration in large-scale distributed science take their cue in part from temporal structures embedded in the organizations and institutions, large and small, that govern and carry out scientific work. These range from the rhythms set by local academic calendars (e.g., the timing of summer and winter breaks), to the rhythms established by the deadlines and review processes of national funding bodies, to the submission and event dates for key academic conferences. For example, patterns of work in many of the biological field stations we study undergo a radical change as winter semesters end and new or returning waves of graduate and undergraduate students arrive to take up summer research projects. Rhythms of fieldwork and analysis may be set in part by the need to hit certain conference or publishing deadlines. At a more local level, timing and patterns of collaborative work may be substantially driven by cycles of preparation and reporting at weekly lab group or individual advisor meetings, and these patterns may shift when such cycles are disrupted.

In a way generically familiar to CSCW and organizational science researchers, the alignment of dissonant organizational rhythms may pose significant collaborative challenges in their own right. Researchers may encounter barriers in working with colleagues at institutions with different academic calendars, whether the distinction between 'quarter' and 'semester' systems in the U.S. or the more radical offset that separates academic calendars

in the northern and southern hemispheres - itself tied to phenomenal rhythms, as discussed below. More prosaic challenges of organizational rhythm may operate at the lab or research group level – for example, the perpetual difficulty of scheduling meetings and joint calls among even a small subset of would-be collaborators. While none of these pose insurmountable barriers to effective collaborative work – and may produce creative work-arounds that leverage rhythmic misalignment to productive advantage – they can play an important role in shaping and constraining the timing and nature of collaborative scientific activity.

Infrastructural Rhythms

A second temporal category emanates from the nature and rhythms of the built environment, including (in our case) the extensive assemblage of equipment and infrastructure attending the production and sharing of ecological knowledge. As work in the history and sociology of technology has shown, infrastructure may embed and embody time in significant ways. Historic investments in infrastructure – from Paul David's classic history of the QWERTY keyboard to Thomas Hughes electrical grids – may build certain forms of stasis, path dependency, and momentum into ongoing efforts at infrastructural development and renewal [10, 22, 12, 24]. The "inertia of the installed base" may lead to material and organizational legacies that continue to shape temporal structures well beyond the point at which the initial conditions that produced them have ceased to hold sway [5, 39].

Beyond these general points about the direction, timing, and consequences of change within infrastructure, we note that infrastructure itself may encode and enforce certain kinds of collaborative rhythms. This is the timeliness of machines, artifacts and systems, from the durability of the Periodic Table of the Elements to the development and operation of the Large Hadron Collider. It is the time of software upgrades, hardware replacement schedules, and the time it takes to build adoption of a new protocol, instrument or standard within a research group or across a field, weighed against the time required to build interoperability between otherwise 'local' systems down the road. Or again: the time it takes for a spacecraft to get to Mars and the window of opportunity before the Rovers go dead.

Such rhythmic properties of infrastructure carry real and immediate implications for collaboration and the organization of social life more broadly. For the latter, consider only the recalibration of social life around 'factory time' in nineteenth-century England, or the role of railways and telegraph in the creation of 'universal time,' arguably the nineteenth century's most important invention [37]. Rhythms of infrastructure also shape patterns of collaboration in our immediate fields of study. A classic example is the legacy and persistence of nineteenth-century systems of classification in the ordering of the natural world. Similarly, behind the recent BP disaster stand not one but two largely separate systems of knowledge: one held by oil companies (who want swift and dirty classifications to check if oil is present) and one held by scientists (whose classification procedures are rooted in an archival literature too slow for the mauls of the driller). In botany we live with and suffer through Linnaeus' ever more baroque and stodgy system of classification, helping to ensure that our species' rhythm of destruction will continue to outpace our rhythms of biodiversity knowledge and preservation for the foreseeable future.

We have told so far what is by many lights a highly recognizable CSCW story – namely, that cooperative activities are shaped at the intersection of social (organizational) and material (infrastructural) orders. We have also provided the outline of an already challenging practical puzzle – namely, how to make the (multiple!) temporal orders embedded in organizational and infrastructural life line up, such that effective cooperative action can ensue. But it turns out this tells only part of the story. We turn now to two additional and widely neglected sources of rhythm that shape and complicate efforts at collaboration in ecology and the earth sciences.

Biographical Rhythms

A third and often forgotten source of collaborative rhythm emanates from the life choices and circumstances of scientific workers themselves. Biographical rhythms have tended to escape classical CSCW and other workplace-based studies in part because of their tendency to spill across the putative line between professional and personal lives (a line we argue that has been too sharply drawn). In this category we see the timing of children, illness and recovery, divorces and new relationships, births and deaths. We see also patterns of activity associated with various stages or moments in the development of biographical trajectories, from the doctoral apprenticeship through the pressures of junior faculty development to post-tenure life, along with rhythms emanating from a variety of less canonical routes (e.g., movements into and out of administration, or back and forth across the lines separating academic from government, industrial, and other locations). Shifting roles, identities, and career trajectories are central constituents of biographical rhythm – though we would note that careers themselves are built and sometimes challenged at the intersection of institutional and biographical time (a point well noted among feminist scholars of work).

Here again we find formative challenges to the nature and timing of collaboration. Patterns of group interaction may

change radically as key participants undergo certain kinds of life transitions – for example, erstwhile post-docs moving into the more constrained temporal structure of junior faculty life (or alternatively: opting for different career trajectories altogether). Collaborative rhythms may be restructured, temporarily or permanently, as key participants move into new parenting roles, deal with long-term disability, come out to their colleagues, or undergo other kinds of life-course transition.

Biographical rhythms may pose certain challenges around coherence in their own right: as scholars from Erving Goffman [16] to Charlotte Linde [28] have pointed out, a great deal of effort may go into the ongoing retelling and repair of coherent life stories, directed to both 'external' (other people) and 'internal' (one's own shifting sense of self) audiences. Individual biographical rhythms may have profound effects on the nature of rhythm in larger collectives. To take a case close to home, our own research team has recently suffered the unexpected death of a loved one and project collaborator. This put in place a whole other set of rhythms – of mourning and remembrance, grief and recollection, care and support, the necessary business attending death – that have come to shape the nature and timing of our own collaborative efforts.

Phenomenal Rhythms

In many of the settings traditionally studied by CSCW researchers, temporal structure could arguably be accounted for by the combination of organizational, infrastructural, and biographical rhythms sketched above. These capture in rough terms the field's traditional concerns with both the 'human' and 'technical' dimensions of distributed collective practice.

In our case, however (and we suspect many others) this human-shaped world tells only part of the story. For in the fields of ecology and the earth sciences we study, important aspects of temporal structure are borrowed and in fact dictated by rhythms emanating from the objects of study themselves. Many such rhythms are seasonal: animals mate, snow melts, and vegetation grows, buds, matures, and declines according to distinctive and sometimes inconvenient patterns. In such cases, collaborative work time is organized in part around the phenomena under study. Other rhythms may be more episodic, 'bursty,' or event-driven in character: in the medical world, teams group and pace themselves around the rate of tumor growth or the speed at which swollen appendices might rupture, and epidemiologists organize their work practices in part with an eye to the spread rate of diseases. Rare but unpredictable events such as cosmic ray bursts, supernovae, tsunamis or earthquakes require rapid mobilization of teams and equipment. Other rhythms may be circadian in nature – for example, the patterns imposed by the nocturnal activities of certain species, or the traditionally night time art of astronomy. Still others impose rhythms of a far more extended or truncated sort – for example, efforts to study long-term climate change, or conversely, the splitting of sub-atomic particles. In these and many other fields, phenomenal rhythms carry deep, immediate and often challenging implications for the nature and organization of collaborative work. And lest 'phenomenal' be confused with 'natural' time, we point out political science as a field both shaped and constrained by the 4-year election cycle.

Moreover, in our formulation phenomenal rhythms are not a reactionary return to objective time, for they too can be acted upon. Elaborate instruments and infrastructures of science are created precisely to manage and manipulate. While apples are perennial, the warm and sunny insides of a laboratory can generate a spring bloom thousands of times a year. Evolution may span hundreds of generations, but exposed to mutagenic radiation (a microwave), fruit fly breeds can multiply in months. Phenomenal rhythms are not fully pliable, they push back and circumscribe action, but with technique and technology can be aligned with other registers of time.

HYBRIDS, TENSIONS, AND ALIGNMENT

While the above heuristics point to collaborative rhythms in their separate and purified forms, temporality in the real world(s) of scientific collaboration and other collective practice rarely shows up in anything like as neat or seamless a form. In practice, collaborative scientific work combines elements of most, and usually all, of the above. The distinctive temporalities attending specific instances of collaborative work are usually shaped precisely at the intersection of often-contradictory tendencies embedded within and between each of the categories noted above. They are also, as the apples in laboratories example shows, acted upon, the object and not merely the backdrop of collaborative activity. This makes rhythmic disjuncture or dissonance a frequent and under-examined tension within distributed scientific forms – and the complex art of rhythmic alignment a much-understudied category of organizational work.

Some such tensions have already been hinted at within the category descriptions given above: the alignment challenges posed by different institutional calendars; the tensions attending choices between short-and long-term costs and payoffs in infrastructural development; etc. Such tensions only multiply as we (as analysts) or they (as collaborative participants) move between the categories. What happens when work moves across the purely conceptual lines distinguishing phenomenal, institutional, biographical, and infrastructural time (or more precisely, where the temporal patterns embedded in each fail to

mesh)? Our fieldwork suggests that the world of collaborative science is in fact rather full of such mismatches, and just as many efforts (small and large, local and systemic) to ameliorate, deal, or simply live with them. We illustrate such tensions with the following set of stories:

Long Term Phenomena and Short-Term Funding

Our first story illustrates a classic tension between phenomenal and institutional time. As academic researchers well know, science has long been funded in short-term chunks, structured in the U.S. around the canonical three-year grant. This poses no particular problems for fields built around discrete experiments – the psychological experiment, the biological lab study, the one-off opinion survey, etc. But what if your phenomenon of study and the methods it requires unfolds on a different sort of timescale (decadal, centennial, millennial, etc.)? For analysts of long-term ecological change, institutional rhythms have long posed a particular challenge. As one ecologist explains,

> Trees grow for hundreds of years, hurricanes may decimate a site every 50 years, and droughts may last for decades; thus, a long-term perspective is needed to understand the ecological response to these slow changes or rare events. [20]

Such misalignments between short-term process and long-term phenomena have led to some famous and costly errors. For example, the 1922 allocations of water under the Colorado River Compact were based on a period in the early twentieth century that we now believe to have been among the wettest in centuries. This has led to the famous problem of 'paper water' (and much work for lawyers) in the American Southwest [23].

The contemporary Long-Term Ecological Research (LTER) Network has emerged as an effort to redress this misalignment between phenomenal and institutional rhythms. Rather than short term grants LTER is reviewed on a decadal basis, and its 26 geographically distributed sites are reviewed every six years. In this manner LTER has itself become a relatively stable institution for ecological research. At the level of the science this has meant longitudinal monitoring of research sites with an emphasis on data curation, sharing and dissemination. Thus, while the majority of research in ecology is still grant-supported, behind these cycles of funding stands an organization oriented and in some small measure aligned with the long-term nature of ecological phenomena. Organizational rhythms have been modulated to the rhythms of the phenomenal world.

Living on Mars Time

Our second story is drawn from the NASA Mars expedition rover (MER) project [as recounted in 31]. Here the rhythms and tensions are multiple, with collaborative activity pulled between the competing demands of phenomenal, institutional, and biographical time. The story begins with a small but important discrepancy: 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. Clocks and wristwatches are redesigned to operate on Mars time. As the mission goes on, members of the MER team literally drift across the Earth day, as the Martian sunrise moves from morning, to afternoon, to evening, and back again.

As the project progresses, strains between this phenomenally structured time and the normal biographical rhythms of the project team begin to emerge. The medical team working with the project notes marked physical consequences for the work team, who begin manifesting symptoms that look like (and amount to) an interplanetary form of jetlag. Such physical problems are joined by even more pronounced consequences for the personal lives of project participants, who find themselves arriving home to sleeping spouses and children one week, and at breakfast the next. As time passes, many participants opt to essentially live at the lab with their temporally aligned colleagues, rather than face a forever-receding schedule back on Earth.

These two vignettes address instances in which one or more of the categories shaping collaborative rhythm are out of sync, with significant consequences for both project outcomes and the lives of the human actors involved. They also speak to the efforts to manage such tensions and discrepancies: in the LTER's case, through the elaboration of new funding mechanisms bringing organizational time into somewhat better alignment with the phenomenal rhythms under study, and in the rover story, through a novel arrangement of project time aligning the Earthly and Martian solar days. In the projects we study, such instances of discrepancy and subsequent alignment work between the different temporal categories outlined here could be proliferated almost without end. But not all such collisions of temporal register are unhappy ones. As the below vignette suggests, there are instances where the rhythms of organization, infrastructure, biography, and the phenomenal world can be made to mesh in happier and more productive ways.

The Arctic Burn

In July 2007, a lightning strike on Alaska's North Slope initiated a rare ecological event: a large-scale fire over Arctic permafrost. For several weeks following the initial

strike, the fire lay down, smoldering away virtually unnoticed in this remote area north of the Brooks Range. But in late August a rare combination of drought, wind, and warm weather fanned the flames, producing what would eventually become the largest recorded fire over continuous permafrost, consuming at its height over one thousand square miles of Arctic tundra. Given the logistical challenges of fire fighting in such a remote region and the relative lack of human infrastructure at risk, the fire was allowed to burn. The flames were eventually extinguished only by the coming of colder weather and the first heavy snows in October.

For the researchers at the Arctic LTER site at Toolik Lake, alerted to the blaze by a helicopter pilot at the station, the fire represented a rare opportunity to study the effects of a major ecological event on the rare and relatively undisturbed ecosystem of the North Slope. But there was little if any hope of studying the fire in process. Beyond the obvious safety issues, the blaze was happening in a roadless area tens of miles from the station: 'close' in North Slope terms, but too far to reach in any simple or obvious way. Helicopter time at the station was expensive, and in any case already allocated to ongoing research projects. The PIs, technicians, graduate and undergraduate researchers on site were similarly already committed, and the prospects of bringing up additional researchers at this stage in the season, even if space could be made for them, were bleak. Nor had the researchers at Toolik Lake (or anyone else for that matter) worked in this particular area before; to be maximally effective, a good deal of baseline mapping, surveying and sampling would be required. Under normal circumstances, the opportunity to capture the crucial first effects of fire on key ecological processes would be lost.

But here the researchers received a rare temporal assist: due to the timing of the blaze and its extinguishment with the fall snows, the fire and its effects were literally frozen in place, for all intents and purposes suspended until the spring thaw. Nutrients and sediment unlocked by the fire would only make their way into the streams and wider ecosystem once the spring run-off had begun in several months' time. Researchers at Toolik Lake used the reprieve to lay groundwork for a comprehensive spring study. A senior PI at the site secured first short-term and eventually longer-term funding to study the burn and its effects. Sampling strategies and research designs across each of the site's terrestrial, land-water interaction, and aquatic ecology groups were developed. Post-docs and graduate researchers were hired, helicopter time was booked, and equipment was laid in. In April, a team of three researchers was dropped at the site, where they camped, did preliminary surveys, and waited for the first pulse of the spring run-off. After several days of waiting, and several additional days of frenzied sampling, the team returned to Toolik Lake with the makings of what they believe will be a major contribution to the field.

Temporal Alignment

In these vignettes we have seen the alignment of rhythms in the lived worlds of collaborative science. While for analytic purposes we have parsed the four rhythms, in practice we see how these are managed and interwoven in unique ways, in part through the purposive actions of individual and collective actors involved. To resolve issues of temporal conflict and fit, participants build instruments and environments, reshape organizations and institutions, and recraft or reorient their personal lives. All of this constitutes what we refer to here as alignment work, understood as the complex set of actions and activities required to bring otherwise disparate rhythms into heterogeneous and locally workable forms of alliance. From this perspective, collaborative rhythms can be made significantly (but not infinitely) malleable. Even phenomenal time can be used, operated on, and leveraged in a variety of ways. The researchers at Toolik Lake took advantage of a unique event beyond their control and the rhythms of the winter freeze to make the best of their limited scientific resources and labor. The Mars Rover team chose to bend organizational and biographical rhythms to phenomenal ones, albeit at personal and organizational cost. A larger set of cases would uncover other instances and patterns of accommodation.

Temporal alignment is therefore a strategic and creative activity. Today we consider the greenhouse and the camera as staples of scientific infrastructure, but in their time they were inventions to manage events too slow (such as growing seasons) or too fast (such as the flutter of a hummingbird's wings) for the pace of research. We ethnographers hardly notice the video and tape-recorders that make it possible to render ongoing talk and gesture into the descriptions, transcripts and codings of ethnographic analysis. These too can be construed as efforts to slow and manage phenomenal time in ways that allow us, personally and organizationally, to catch-up.

DISCUSSION

The categories and stories offered above provide a taste of the complexity of temporal dynamics at work in our studies of collaboration in ecology and the earth sciences. They also suggest a number of additional features of rhythm with important implications for CSCW and wider social science scholarship.

First, as alluded to earlier, all rhythms are specific, emerging from discrete sources and structured according to particular patterns; and multiple, showing up in messy and heterogeneous form and rarely if ever alone. The first property sets rhythm apart from the more formalized and abstract categories of time used to mark and track them.

The second points to the real-world difficulty of isolating rhythms in discrete moments, or encountering 'individual' rhythms in anything like a pure form (more on this below). From this perspective, any given site, activity, or moment may be best thought of as a conduit or gateway through which multiple rhythms are flowing at once, many of which will be contradictory or dissonant in nature. Our own examples have tended to weight phenomenal over other kinds of rhythms; this is partly due to our own sense of what's most temporally distinct and interesting about the rhythms we encounter, but also our belief that phenomenal and biographical rhythms have been relatively neglected in CSCW work to date. But one could easily pick cases that show different rhythmic configurations, or where configurations change over time: for example, the way in which harvest-based academic schedules have come to shape and constrain experimental field practice, including in the agrarian research settings whose patterns first gave rise to them.

Our second point concerns the distinctions and oppositions we are trying to avoid through the concept of rhythm. One of these, referenced above, is the subjective/objective split long dominating discussions of time in social theory (and some CSCW work drawing on these traditions). From this viewpoint, time appears in one of two guises: as a neutral and abstract category, impinging on collective activity as an external and uncontrollable force; or as a purely 'subjective' phenomenon, bound and constituted at the limits of the perceiving subject. We wish to argue that time is both more and less malleable than that: more because most rhythms that impinge 'as if' from the outside of collaboration are in fact more specific and historical than the abstraction of objectivity would suggest; less because even 'subjective' experiences of time run up against limits and resistances grounded in a world external to individual and collective subjects.

Our own pragmatist solution to this dilemma is to treat rhythms as we and our actors encounter them in the world: as 'real in their effects' [cf. 25]. This acknowledges the given quality of rhythms as patterns and limits encountered by actors in the world. But it also recognizes rhythms as meaningful phenomena, caught up in the world of perception, interpretation, and experience (a point roughly captured at the individual level in Reddy et. al.'s description of temporal horizons [36]). This opens up certain representational or imaginary dimensions of time as proper and indeed central topics of rhythmic analysis – for example, the way in which actors deploy and account for origin stories, life histories, and projected futures in orienting individual and joint action in the context of given collaborations. It also repositions rhythm and time itself as an active and ongoing *object,* rather than passive backdrop, of collaborative work.

For the same rough reason we are leery of efforts to draw too sharp a line between individual or personal rhythms and those of wider collectives. Here again the danger is the separation that denies connection, or naturalizes difference to the level of the individual. Individuals can become more (or less) deadline-driven in consequence of their participation in collective efforts. Existing diurnal patterns and preferences for work ('morning' vs. 'night' people) may be adjusted to mesh with the temporal needs and patterns of the group. Synchronization can also work in the other direction, with new team members bringing new rhythmic patterns into the group and thus shifting rhythms across collaborations as a whole.

Third and finally, the ability to manage and orchestrate the multiple rhythms transecting any form of distributed collective practice may constitute an important site of authority, power, and control. Projects willing to wait for contributions from senior PIs and other key participants may be less tolerant of delay on the part of graduate students, technicians, or other staff. Scheduling conflicts may be resolved in favor of senior or more centrally placed participants over junior or more peripheral ones. Gender effects may play out through the challenges (accommodated or not) of aligning obligations of parenthood, care giving, etc. with organizational, infrastructural, or phenomenal rhythms. Under conditions of dissonance and unequal distributions of authority and control, the question of which rhythms are adjusted to which (and *whose* rhythms to *whose*) turns out to be an important site for the exercise of power and control.

CONCLUSION

The preceding analysis offers one fruitful way of opening up the problem of time in collaborative scientific practice, with theoretical and practical implications for the field of CSCW as a whole. The paper has sought to provide an initial account of the temporal rhythms and challenges that may structure collaborative scientific practice – a point meriting further attention within CSCW and the social sciences more broadly. In particular, we have argued for the salience of four distinct kinds of collaborative rhythm – organizational, infrastructural, biographical, and phenomenal – and called attention to the ever-present work of alignment required to bring these into locally workable arrangements. This represents a first pass at what we envision as a much longer-term program of theoretical, ethnographic, and design-based work.

To achieve this, researchers must confront three immediate methodological challenges. The first we'll call *problems of complexity and duration*. Put simply, there is an enormous amount of rhythmic action going on at any time in collaborative settings, and knowing as analyst or designer what, where, and when to follow can be an enormous challenge; time may indeed be a river, but as

any kayaker or first-year hydrology student will tell you, rivers flow at different speeds, in different layers, and in many different directions at once. Part of our purpose in this paper has indeed been to show this blended, layered, and every-which-way-at-once quality.

Our second category we'll call *problems of weak and partial traces*. This stems from the fact that much of what we care about as rhythm leaves few obvious tracks to follow (time is a river in that way too). An important exception, exploited in some of the CSCW literature reviewed above, concerns forms of electronic activity (emails, online calendars, wiki or Facebook edit histories, etc.) that may accompany collaborative work, leaving accidental archives in their wake. These pose important opportunities for the field, and we welcome recent CSCW work and tools exploiting these possibilities. But in the worlds of collaborative science we study (and we believe other contexts) they may offer a limited and highly partial perspective on the full range of rhythms in play.

Finally and most generically, we offer *problems of change and emergence*. Here we encounter questions not just of how rhythms shape and constitute ongoing patterns of collaboration in given settings, but how processes of collaboration themselves can in turn reshape the rhythmic circumstances that constrain them. Problems of change and emergence are clearly tied up in questions around complexity, duration, and partial traces noted above. But they also implicate a much wider and equally challenging set of theoretical issues: problems of agency and intent; problems of structure and determinacy; and the problems of power and control noted above.

The present paper has offered a first introduction to such issues in the worlds of collaborative science we study. Future work will carry this forward into additional theoretical, methodological, and design interventions.

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