Dynamic Reconfiguration in Planetary Exploration: A Sociomaterial Ethnography

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Abstract: In taking into account the ways in which material and social realms are constitutively entangled within organizations it is rhetorically tempting to say that technologies and social structures reconfigure each other. But what does it mean to reconfigure? How does one 'figure' the other and how do we fully embrace a mutually constitutive relationship when examining fluid relations? This paper delves into these questions by exploring how physical, social, material, technological and organizational arrangements dynamically reconfigure each other in the durée of organizational practice. Using the venue of space exploration, we present three empirical examples from an ethnographic engagement with a NASA mission orbiting an outer planet in the solar system to examine various configurations and sociomaterial relations. In this endeavor we suggest that theoretical and empirical traction can be gained by focusing attention on the dynamic reconfigurations between social and material realms. In so doing, we call attention the various ways that current sociomaterial perspectives have difficulty articulating the shifting, figural, asymmetric and dynamic negotiations between people, social structures, information technologies, and representational objects. This paper contributes to current discussions of sociomaterial relations in information systems research by presenting an empirical treatment of entangled and shifting re-configurations and providing language for engaging with this perspective.

Keywords: Sociomateriality, Dynamic reconfiguration, Organizational processes, Software studies, Representational practices, Outer planetary exploration, Qualitative empirical analysis

Introduction

Recent interest in sociomateriality as a consideration in information systems and organizational studies can be placed in a broad historical context. Numerous articles review the evolution of scholarship on the relationship between organizational processes, human action, and technology (Leonardi et al. 2010; Leonardi et al. 2008; Markus et al. 1988; Orlikowski et al. 2008; Rose et al. 2005; Rosenbaum et al. 2009; Woolgar et al. 1991; Zammuto et al. 2007). This scholarship generally concurs that early writings on the intersection between information technologies and organizational practice often suffered from a somewhat naïve technological determinism, directly linking technological opportunities with organizational transformation. Subsequent studies, which we might broadly call social constructionist, attempted to counter these technologically determinist narratives by drawing attention to the social forces that shape the application, interpretation, and use of technologies. These treatments emphasized the role that social norms and social practices play in how technologies are used and 'enacted' within organizations. While this was a crucially important move, it sometimes wrote the capacities and constraints of technology out of the picture altogether.

Interest in sociomaterial analysis, then, attempts to reconsider the relationship between social and material considerations in the emergence and evolution of organizational practice, bringing back into focus the material specificities of physical and technological arrangements. In this vein, one of the primary concerns within the recent literature on information technology in organizations has been the question of where to locate agency (Boudreau & Robey, 2005; Leonardi et al. 2010; Leonardi 2011; Rose et al. 2005; Rosenbaum et al. 2009; Volkoff 2007; Zammato et. al. 2007). From this view, scholars attempt to balance examinations of the social dynamics of how technologies are received and interpreted with an aim to better understand how they might "resist" human agency – constraining or affording action through their material properties. These perspectives proceed from the recognition that, while the emergent and entangled nature of practice and technology has been successfully demonstrated, we must further elucidate the particular ways that the social and material become entwined. While this scholarship notes that the line between the social and the material is a blurry one, treatments nonetheless tend to imply that scholarship is best served by distinguishing them as domains in order to to understand how they become interwoven. While often encountered in complex interplay, material and social influences are taken, then, as concerns that might yet be unraveled and separated (Leonardi et. al. 2008; 2010). The most recent suggestion to embrace a 'critical realist' perspective in articulating sociomaterial relations typifies this thrust (Leonardi 2013; Mutch 2013).

Indeed, the term "sociomaterial" itself is potentially misleading here, since it seems to frame the social and the material as different and distinct domains, suggesting that the goal is to draw the appropriate boundaries, identify material features pliable to social norms, or expose social norms that sediment otherwise flexible materials. The bigger challenge is thus to examine the thoroughgoing mutual constituency of social and material arrangements that was emphasized in initial theoretical calls for a sociomaterial perspective in information systems and organization studies (Dale 2005; Orlikowski 2007; Orlikowski et al. 2008). From this vantage point, "social" and "material" are each simply selective projections of a tangled whole. As Orlikowski and Scott noted in 2008, "Entities (whether humans or technologies) have no inherent properties, but acquire form, attributes, and capabilities through their interpenetration. This is a relational ontology that presumes the social and the material are inherently inseparable." (Orlikowski and Scott 2008 pp. 455-456). What is thus needed for future research that takes a sociomaterial perspective is "to develop nuanced language that does not betray [this] relationality" (Wagner et al. 2010, p. 292) and to articulate this theoretical insight in empirical settings, which has proven an ongoing challenge (Mutch 2013).

These broader challenges frames our paper. Contributing to the relatively small number of empirically driven papers that attempt to fully engage with mutual constitution (e.g. Nyberg 2009; Wagner et al. 2011; Wajcman et al. 2011; Scott et al. 2012), we provide a language to analytically explore co-constitutive relations. We take as our analytic starting point the concept of "configuration" drawn from feminist scholarship in Science and Technology Studies (STS) (Barad 2003; Cetina 1999, Haraway 1997; Suchman 2007; Suchman 2012). We find that configuration offers an alternative perspective on sociomaterial agency. Rather than focusing on the distinct attributes of material and social agencies, configuration takes up the question of how such bounded categories of the social and the material, and the agencies attributed to them, are co-constructed (or con-figured, that is, figured together). This lens also takes as granted the emergent and entangled nature of the sociomaterial relationship. However, in so doing it also emphasizes the open-endedness and ambiguous nature of such categories as "the social" and "the material" in the first place.

This lens helps us to see past categorical debates about what types of agencies or phenomena, social or material, influence outcomes, and instead ask when and how such categories "become salient within particular fields of action" (Suchman 2007 p. 1). When we take this perspective what is at stake is not the locus of agency, but rather the question of how "arrangements that produce effective forms of agency" (IBID p. 242) emerge in ongoing work. Suchman, quoting Barad, notes that "agency is not an attribute but the ongoing reconfigurings of the world" (IBID, p. 259 citing Barad 2003 p. 818). Reconfiguration, then, denotes the *process* in which new assemblages of agency emerge.

The process of reconfiguring, as a key analytic consideration, focuses our attention on the shifting conceptualizations of the social and the material – the open-endedness and availability of these categories to be reworked. Thus, we focus on this *process of dynamic reconfiguration* – the ongoing, shifting, and open-ended work to delimit and define the social and the material and the relationship between them. Social and material are each figured in relation to each other, and in relation to the phenomenal objects of work practice, in an ongoing manner. Our aim is to contribute to the empirical understanding of this *process of dynamic reconfiguration* and in particular to demonstrate the work of "figuring" that is at its core.

Scholars have previously discussed how technologies, social relations, and organizational structures 'reconfigure' each other in the more colloquial sense (Barley 1986; Dale 2005; Huber 1990; Leonardi 2013; Leonardi et al. 2010; Orlikowski et al. 1995; Scott et al. 2012; Wagner et al. 2011) and there is a long line of work based on organizations 'reconfiguring' themselves to keep up with changing environments (Aupperle 1996; Teece et al. 1997). The word is useful. It captures something of the adaptability of social processes while speaking both to the flexibility of information technologies and to the organizational effort to make change happen. However, we believe that to speak so casually and easily of configuring and reconfiguring masks some important concerns that we seek to examine here. Our examination of *dynamic reconfiguration* is unique in the direct focus on the relationships and assumptions embedded in these terms, the multiple meanings of the root 'figure,' and how this language can be used to gain purchase on sociomaterial relations.

Our investigation is grounded in a long-term ethnographic study of space science. The material we present here is drawn from ethnographic fieldwork conducted between 2009 and 2011 at a project we call "the Mission," a decades-long deep space science mission directing a robotic spacecraft currently in orbit in a planetary system in the outer solar system. Figures and figuring are central to the daily life of the Mission, in the most mundane ways – numerical figures, mathematical figures, graphical figures, algorithmic figures, representations, images and encodings that constitute and produce the relationship between "here" and "there." It is through the production and reproduction of these arrangements – that is, through occasions of figuring, *con*-figuring (figuring with), and *re*-configuring (doing so again and again) – that sociomaterial practice takes shape.

This perspective naturally draws our attention to the centrality of representations (Daston et al. 2007; Latour 1990; Latour et al. 1986; Lynch 1985; Lynch 1988; Vertesi Forthcoming). As Woolgar has noted, configuration is a process in which representations and their contexts are mutually constituted

(Woolgar 1991). In our fieldwork, representations such as numbers on a screen, simulations of the craft, and navigational charts are key figures in the sense that they provide the capacity to visualize and manipulate the distant craft and make a completely virtual environment (space) amenable to action. Representations, however, are more than maps (Berg 1997; Pollock et al. 2012). Representations also participate in the processes of figuring, as they draw attention to particular features of the domain, reproduce the conventions of scientific practice, and create a series of abstractions that are the focus of scientific discourse.

Therefore, while representational figures are key, figuring extends beyond objects, images, and texts. For example, the computer running algorithms to calculate trajectories of the space craft is doing figuring work: these processes of figuring are happening in relation to, but also in excess of the machine's final output, the representational images. They are also happening in light of, but independent from, the software engineers and navigation team who wrote the code and engage with the algorithms. Figuring as a process thus includes but is not limited to producing figures. People may 'figure' their worlds, but the various routines, machines, and objects are actively figuring as well. This can be seen clearly in empirical moments of organizational life.

A Moment of Reconfiguration

Several spacecraft engineers keep an eye on the screens they have configured to show only the spacecraft telemetry data relevant to their particular subsystem. Upstairs, an ACE (Aerospace Communications Expert) locks in control of an antenna in Goldstone, CA after confirming the proper configuration of data rates and time allocations with the DSN (Deep Space Network). Commands to conduct scientific observation, navigation maneuvers, and health and safety checks will be radiated via microwave beams to the spacecraft that has been orbiting the planet for close to seven years. The commands radiate to the craft and everyone sits tight waiting for the three-hour round-trip light-time before they will get confirmation that commands have been received and executed properly on board the craft. As the bits rain back down to earth, scooped up by the antenna, the screens become active, showing contact has been successful. These commands are sent using one of the most well known symbolic systems, on/off, yes/no, zero/one, the information bit – a system scalable, durable, and deceptively robust. However, it is also precarious. For in deep space a zero is not always a zero.

Occasionally a bit gets flipped. The engineers spot something unexpected on the screen indicating a problem encountered by the spacecraft. They analyze the spacecraft data in order to deduce the cause of some anomalous behavior. They run tests in the basement laboratory that contains a simulation of the spacecraft's on-board computer systems. And after much research they figure out that a bit has flipped. A high-energy particle traveling through deep space – a "cosmic ray" – has intercepted the bits transmitted from earth, turning a zero into a one and, in a very real sense, reconfiguring how those on the ground orient to and understand the craft in space.

Dynamic reconfiguration, as we take it up, is key to explaining the 'bit flip' anomaly described above. In our scenario, cosmic rays physically disrupt the microwave radio beams transmitted from a Deep Space Network antenna, altering the bits radiated to the craft. Consequently, the codes that the craft is programmed to interpret are altered and the apparent 'misinterpretation' by the craft of commands from the ground (which was, in fact, an accurate interpretation of the flipped bit) instigates a process of reconfiguration of the way the craft is understood and represented to those charged with its care and maintenance. The spacecraft engineers perceive an anomaly and, in order to make sense of what is happening, enact a process of reimaging and reimagining the craft looking for the source of the anomaly. Could it be a bad file sent to the craft? An error introduced into the spacecraft software in an update? A manifestation of some unknown bug in the spacecraft's operating system that is only just now surfacing?

Throughout this process, scientific phenomenon, hardware, software, and data are reconfigured in fluid and shifting ways. In one moment the spacecraft is an instrument gathering data about scientific phenomena through the arrival of bits radiated from the craft. In the next the craft is the object of concern as the engineers use the same bits to attempt to understand the craft's behavior. In this reconfiguring of the craft the bit is first taken as information that can be used to trace out the source of the error introduced into the code. However, after numerous checks and tests, the physical qualities of the bit become manifest. Once the bit becomes reconfigured as a physical entity it can be subject to the same contingencies as any physical object in outer space – thus it is a thing that can be 'flipped.' In fact, as one engineer reflected, the bits themselves provide a relatively sensitive instrument for measuring the occurrence of cosmic rays in outer space. We can now see that the bit is simultaneously information, physical entity and an instrument that, in turn, reconfigures broader understanding of space and the forces of energy and transformation that we call cosmic rays. Key here, however, is noticing when and how each of these ways of figuring the bit are called to the fore and how each participates in the sociomaterial assemblage.

The vignette illustrates the variety of reconfigurations in play at any one moment of sociomaterial engagement. An anomaly occurs, revealing an unpredictable and ongoing process of reconfiguration in which figures - models, representations, and imaginings – are interpreted in open-ended and shifting ways. In addition, this example highlights reconfiguration as an organizational process that incorporates an anomaly into a sociomaterial understanding of work practice. The engineers enact practices that have emerged over the life of the mission. Practices that allow them to assess, label, and create a legitimated account of the uncertainties emerging through communication with a remote and semi-autonomous machine. This process calls upon knowledge of the spacecraft across time and space – bringing together diverse perspectives from design, engineering, and operations to re-imagine, or imagine-again, the craft and its behavior.

Once these parties label a 'bit flip' as the source of some unusual behavior, they are then able to address the problem and achieve an organizationally satisfying resolution. Pinpointing 'bit flip' as the problem allows the engineers to move on and send new commands that redirect the craft. And, while the engineers are reconfiguring the craft in their imaginations and actions, the craft is humming along, responsive to its own routines and temporal rhythms, and to the commands radiated three hours prior.

In this paper we use three empirical examples drawn from a broader ethnographic engagement with a decades-long mission to the planetary system to empirically examine co-constitutive sociomaterial relationships as part and parcel of organizational practice. Although derived from the same setting, the empirical cases offer three distinct but complementary sociomaterial portraits. One case illustrates how new organizational requirements drive the introduction of new software and, in so doing, reconfigure the relationship between the craft, its navigators, and the organization more broadly. Another illustrates how a perceived physical failure of the craft triggers new understandings of the craft that substantially reconfigure organizational processes. Finally, we offer an example of how an organizational reconfiguration (a single person leaving the project) hampers the capability to represent and visualize the craft in orbit, triggering new interplays between ground staff and the craft. Together these empirical examples suggest that reconfiguration emerges dynamically, without planning or mandate, and can be sparked by any number of triggers, including, but not limited to, organizational mandate, physical breakdown, or movement of individuals.

This endeavor contributes to current scholarship by offering a theoretical articulation and empirical illustration of the deeply constitutive relations that are organizational/technological/material entanglements. Setting aside debates about whether or not it is best to approach sociomatieral perspectives from a 'critical realist' or 'agential realist' perspective (Leonardi 2103; Mutch 2013), we aim to provide an example of how to gain empirical traction on the theoretical insights heralded by sociomateriality and, in so doing, add to the methodological tool kit of scholars who embrace this perspective.

Specifically, the language of *dynamic reconfiguration* offers a productive lens for thinking about and researching the nature of materiality of organizational practice that will influence future attempts to ground theoretical perspectives in a manner that honors the shifting and asymmetric relationships between the various hardware, software, people, logics, structures, and routines that reconfigure each other.

Research Setting

The illustrative examples presented here are drawn from ethnographic fieldwork conducted at a project we simply call "the Mission" located at a premier NASA-contracted laboratory during 2009-2011. Launched in 1997, the spacecraft that is the focus of the Mission's activities has been orbiting a planet in the outer Solar System and collecting scientific data since 2004. The Mission is large, costly, and complex compared to other missions at the laboratory. While the Mission has, over its lifetime, employed more than 500 individuals, it currently comprises a team of just over 200 people. The Mission is currently in its third phase – lasting from 2010 through 2017 – at which time the spacecraft will be disposed of by deliberately impacting the planet's atmosphere, gathering data as it goes. The transition to this final phase of the mission, which occurred during our research, resulted in a quarter reduction in funding and personnel.

Among the various teams observed at the mission, those relevant to this paper are the Spacecraft Office (SCO), Navigation (Nav), Science Planning and Sequencing (SPS) and Mission Sequencing Subsystem (MSS) teams. SCO is responsible for the health and safety of the spacecraft and for the execution of science and engineering activities on board the craft. Among other responsibilities, SCO must take the designs for science observation activities and translate these into commands, checking these against numerous flight rules to ensure safe and proper execution by the spacecraft. The Nav team is responsible for designing the "tour" trajectory that the spacecraft will follow as it orbits the planetary system and actively flying the craft along this trajectory by conducting space flight maneuvers on a weekly basis. The SPS team works to manage and integrate the scientific activities produced by participating scientists distributed across institutions in the US and Europe. And the MSS team oversees the development and maintenance of "ground" software (as distinct from "flight" software on the craft) to support the sequencing of science.

We chose to draw upon illustrative examples from this field site because the nature of the setting calls into relief sociomaterial relations between information technologies, the physical aspects of the craft, and organizational processes. For example, the Mission must grapple with the remoteness of the material spacecraft in both time and space. Traveling at the speed of light, radio signals take around 90 minutes to cross the distance between Earth and the spacecraft, which means that there is a three-hour delay between sending a command and receiving confirmation from the craft. The Mission must also contend with technological legacies of varying rigidity on board the craft and on the ground – its current technological infrastructure must be compatible with hardware and software from the 1990s and early 2000s. Information technologies and various software tools mediate how the team on the ground directs the craft, perceives what is going on in space, and frames opportunities for location, movement, and data capture. And finally there is the spacecraft itself, executing a complex flight plan while in constant motion – in a forever changing state of movement and physical decay. These extreme conditions expose the sociomateriality of information and break down basic assumptions about information technology – the immediacy, instantaneity, and immateriality of information.

Data Collection and Analyses

The empirical examples presented here are drawn from nine months of ethnographic fieldwork at the Mission carried out by the second author. The fieldwork was conducted during two periods. The first, June-July 2009, aimed to provide a broad understanding of the engineering work at the Mission, such as how scientific objectives are implemented into a series of commands and the role of the Mission infrastructure in the interactions between Science Planning and engineering teams. This preliminary study informed a second, more in-depth round of fieldwork, from January to August 2010, from which this paper draws the bulk of its data. The earlier study revealed a dense and layered ecology of software tools at the Mission that prompted a greater focus on the role of software use and development and the use of additional data collection techniques described here.

Data collection methods included semi-structured interviews, participant observation, informal conversations, shadowing of work, software walk-throughs, and software mapping. Table 1 provides a full breakdown of data collection in this field-site. Construing the fieldwork as ethnography of software proved to be a rich methodological approach for studying the Mission organization from a sociomaterial perspective and providing a unique lens into organizational relationships. By focusing on software, a relatively innocuous term at the Mission (software is not the primary objective of their work yet everyone works with software), we learned about the everyday mundane experiences people have with software tools. Asking for oral histories of how software evolved also provided insight into accounts of the sociality of the organization across time. This technique helped surface reflections about informants' understanding of their own work and the work of others as well as identify the horizons of informants' knowledgeability about software tools on the Mission. Individual informants could then recommend other people to speak to about these tools that were peripheral to their own work. This proved a useful technique because it opened up responses from informants about the role of software in their own work but also revealed (unexpectedly) the ways that software mediated how people understood organizational roles and relationships.

We also took pictures or collected copies of a variety of organizational artifacts such as calendars, schedules, newspaper articles people were reading, mission planning documents, outreach materials, software diagrams, organization charts, comics, commemorative posters, personal photos on the walls, models of the spacecraft, technical drawings, toys, trophies etc.

<table>
<tr><th colspan="2">Table 1: Data Collection</th></tr>
<tr><td rowspan="2">Interviews.
Interviews were conducted with 30 key informants twice, both during the initial and final months of the fieldwork, to first get a sense of the overall work of the Mission and then to provide more in-depth follow-up through oral history interviews. Initial key informants were drawn from the managers and leads of the various Mission teams and then were identified via snowballing (asking informants for recommendations of who to speak to) and by identifying informants cognizant of particular work issues that emerged during the course of observations.</td><td>Oral History Interviews: In-depth interviews utilized software as a lens into organizational practices and relationships and drew on oral history interview techniques around questions such as: What work do you do at the Mission? How did you come to work at the Mission? What software tools do you use? How have the software tools evolved over time?</td></tr>
<tr><td>Software walk-throughs and diagramming: As software tools came up during interviews, informants were asked to walk the ethnographer through the software tools to demonstrate the tool's functionality and work flow. Approximately 10 informants were also asked to sketch a diagrammatic map of the software tools used at the Mission.</td></tr>
<tr><td rowspan="3">Observations.
Observations were conducted 3-4 days per week, typically from 8am to 5pm each day. Observations included focused observations – dedicating time with particular teams (SCO, Nav, IO, MSS, and SPS) for three to four weeks each – and sitting in on approximately two hundred formal and informal meetings. These included teleconference meetings with representatives from remote science and instrument teams (30+ people), weekly and daily team status meetings (15-20 people), regular meetings such as to review commands, software changes, and products of science planning and sequencing or navigational work (20-30 people), ad-hoc "tag up" meetings (2-6 people) to trouble-shoot emergent problems, and meetings attended by Mission personnel such as lab-wide celebrations and presentations (~200 people) and "section" meetings for navigators or software developers (~20 people).</td><td>Work shadowing: The ethnographer observed approximately 10 people during the course of their daily work for a couple of hours each, sitting with individuals in their cubicle, taking notes about the activities performed and software tools being used and asking occasional questions to clarify what the informant was working on or doing.</td></tr>
<tr><td>Trace observations: Observations following processual sequences of work activities such as the process of translating a sequence from science designs to commands.</td></tr>
<tr><td>Participant observation: The ethnographer sought out opportunities to participate in the ongoing work of the Mission. The documentation of software tools at the mission was obsolete, so the ethnographer was able to incorporate some of the observational and interview work into the larger aim to get a sense of the software tools being used at the mission by working closely with the ground systems engineer. This also resulted in participating in meetings held among long-time Mission staff (some of whom no longer worked on the Mission) to recollect as a group how the software tools evolved over the course of the Mission where the ethnographer aided the process by asking questions to the group and providing her own maps of the software tools to the group to prompt reflection.</td></tr>
</table>

Ideas for this paper were formulated while the second author was still in the field collecting data. In the course of weekly discussions about the ongoing fieldwork, sociomateriality came up as a theoretical lens to approach the data and the complex role of software in the mission. In order to test the robustness of this concept we identified several empirical case studies that revealed moments of change, evolution, restructuring and re-imagining in the relationships between the craft, the software, and the organization. In the course of dialoguing about moments of sociomateiral reconfigurations we quickly noted that each moment emerged dynamically from various triggers and revealed diverse relationships between software, hardware, organizational practices, and social structures. These examples became the basis for this paper.

Once these empirical moments were determined to warrant further analysis we reviewed all related field notes and transcripts. We met regularly over a period of five months to brainstorm as a group about how these examples illustrated sociomaterial dynamics and challenged current ways of thinking. During this time the ethnographer wrote multiple memos about each empirical moment. Each author then read and interrogated these memos (and each other) in order to tease out embedded assumptions about linearity, inherited agency, and cause and effect. We then wrote a narrative overview of each of the case studies taking the perspective of how various players such as the organization, the craft, the individuals involved, and the software might 'see' the story. Then we teased apart each of the constitutive elements within these stories and analyzed how they related to each other. This process produced the descriptions of the illustrative examples discussed in detail in the following section. In addition to inductively analyzing the data we did extensive reading of sociomaterial and STS literatures. The interplay between the empirical examples and the language and concepts we were exposed to in various literatures led us to turn to *dynamic reconfiguration* as a fruitful analytical and theoretical tool for approaching these data.

Empirical Examples

The following section discusses three examples pulled from our empirical data. In the emic moments of dynamic reconfiguration described below the sociomaterial landscape shifts, and the delicate relationship between machine, organization, and people is, once again, renegotiated. As such, these examples are merely that – illustrative discussions of the entwining, shifting, and negotiated sociomateriality that we argue is a pervasive organizational reality. Such 'moments' only serve to throw into stark relief the elements of the sociomaterial ensemble, the constantly shifting relations among them, and the processes by which the 'social' and the 'material' are called into being.

Example One: Navigating the craft

The Mission involves uniquely complex navigation throughout its lifetime. Unlike single-shot missions where a craft is hurled into outer space (Voyager) or landing missions that land a craft and then maneuver it across a planetary landscape (Mars Rovers) this mission involves continuous navigation of the craft on its "tour" through the planetary system. This is the only mission in NASA that is currently steering itself around a planetary system on a weekly basis. As several members of the team mentioned, they must accomplish regularly the number of maneuvers that others produce over the course of an entire mission.

The work of navigating the spacecraft involves ascertaining the spacecraft's position and velocity, analyzing potential maneuvers, attending to fuel consumption, and developing on-the-fly solutions to either maintain the spacecraft on its designed tour or respond to changes in scientific priorities. At the same time, Nav works with the SCO and the Science Planning team to facilitate the scientific discovery that is at the heart of the mission. The same thrusters, reaction wheels, and vectors used to navigate the craft are also used to point its science instruments at interesting data targets.

All of these navigational activities are achieved with the aid of a complex set of software programs that provide the logic, vision, and tools by which navigators understand the environment of the craft, determine their current orbit, and analyze potential maneuvers to achieve the next desired orbit. In a real sense the navigators can only come to know the spacecraft's position and path via this software. As one team member put it, the work of determining the spacecraft's orbit is "figurative," for on a day-to-day basis they only know where the software says that it is. The shared understanding of how the software works defines the space of opportunity for navigators; mediating what they believe is possible and controllable, and producing the graphical figures that enable managers and others to trust this shared imaginary. These navigators are under extreme pressure to protect and direct the craft (avoiding collision with another body in the planetary system and making sure the craft does not spin out of orbit) all the while performing intricate maneuvers so instruments are able to capitalize on small windows of opportunity to capture scientific data.

The Nav team also plays a role in organizational processes more generally. Beyond directing the craft, navigational software produces abstract figures for the organization – graphical images that plot Doppler patterns, fuel consumption, and vector trajectories. Key to organizational functioning is the consistency of these figures, which act as boundary objects throughout the organization. Different teams rely on the figures developed by the Nav team to assess proposed actions and plan future stages of the mission. The Mission conducts maneuvers in close proximity to each other and the organization makes decisions under tight timeframes. Navigational figures that assist with communication, prospective analysis, and approval processes are considered valuable organizational artifacts. As such, it is assumed that these graphs and charts should maintain a consistent look and feel.

Given this overview of the role of navigational software in the mission, it should not be a surprise that "upgrading" to a new suite of navigational software tools was, in no uncertain terms, a big deal. The requested upgrade was part of a laboratory-wide effort to shift mission projects to centralized software resources for both navigation and ground support that are easier and less costly to maintain. The request to upgrade to the new "Mission analysis and Operational Navigation Toolkit Environment" (MONTE) software system required that the Nav team assess, set-up, and understand entirely new software while the craft was speeding through space and conducting multiple maneuvers. The team clearly could not slow down to experiment with the new tool.

Implementing the new software turns out to be no easy feat. The legacy and new software systems are written in different languages (FORTRAN/perl and C++/python respectively) and are based on different algorithms for calculating orbits. Regardless of this lack of translatability between the two software tools, the Nav team was forced to assess how inputs they were familiar with from the old software related to inputs required for the new software. Further, they were expected to negotiate a discrepancy in outputs that did not converge on the same solution.

The mission has refined its knowledge of the planetary system and its eccentricities over time as it collects science and engineering data about the contours of dust, rings, atmospheres, and positions of various bodies. However, all of this seemingly “objective” knowledge is only known through the tools that enable them to see, assess, and calculate astral bodies. The planetary system is thus reconfigured via the software tools that allow us to physically go there, “see” the planet according to the instruments on board, measure it according to certain logic of imaging and measurement, and create a shared sense of what “it” is. What happens to this knowledge when the logics of the apparatus changes? This is the conundrum the navigators were left with.

Initially, the Mission attempted to align the two software tools by translating knowledge embedded in the legacy software into a form that aligned with requirements and inputs for using MONTE. The FORTRAN-based legacy software had been around for a long time, with its earliest versions developed in the 1960s. The legacy software was written to run sequentially through a list of calculations and algorithms, so the years of accumulated knowledge about flying the spacecraft was embedded throughout the code as parameters were tweaked based on new data and refinements of their models. At first the navigation team focused their effort on reverse engineering the legacy code in order to get the correct inputs for MONTE. However, this initial attempt to locate all the constants embedded into the legacy software in order to transpose them to MONTE was set aside as it became obvious that some of the differences between the systems, such as how each language stored and computed numerical data, rendered direct translation untenable.

In order to ensure that outputs would align with other organizational tools and procedures, the Nav team needed to make sure that solutions it produced with the new software adhered to global software interface specifications. However, the team soon realized that the new software did not produce appropriate output products. This required them to dig deeper into the algorithms of the new software to understand these discrepancies. Meanwhile, the navigators began to engage in duplicate efforts. It was determined that the only way to maintain operating knowledge of the craft and expertise in directing, protecting, and navigating was to run the tools side by side. The navigation team thus entered into a “parallel operations mode” that simultaneously used both sets of software even as each tool produced different outputs. The initial plan was to operate in full parallel, with every iteration of orbit determination and maneuver design completed on both sets of software, for several months before “going the full MONTE” and making the final switch. Years later, the team has yet to find the MONTE software stable enough to make the move as new versions are released every few months.

The differences between the solutions generated by MONTE and by the legacy software are caused by the use of different algorithms, programming languages, and ways of processing information. As one navigator explained, with all of the parameters that are being modeled it is almost impossible to discern how one single parameter impacts the end solution let alone how all the differences impact the solutions. “It is a very big game and [each system is] their own universe. Each [solution] is correct in its own universe. And these two solutions know nothing of each other.”

The navigation team is repeatedly engaging in maneuvers and flybys that have never been done before. Therefore, the assumption that, over time, navigators will be able to direct the craft, figure the planetary system, and accurately “read” solutions from MONTE is challenged by the fact that the inherent dynamism of the mission means that there will never be constant set of “routine actions” by which the relationship between the legacy software and MONTE can be fully assessed and understood.

From an organizational perspective, MONTE also challenged the articulated and objectified knowledge that had become implicated in organizational processes more generally. According to one navigator, the most difficult aspect of the change was allowing for the differences in logic when producing the plots and graphs that the organization has integrated into decision-making processes across teams. As one navigator explained, when members of his team say that the new software does not work it is because it does not work "like" the legacy software. The boundary objects have changed and the organization must learn to re-communicate using new artifacts. This calls into question how other teams assess what the craft can do, the most effective and efficient moves, and the overall assessment of priorities and objectives.

In this example we want to draw analytical attention to how MONTE reconfigures not only organizational dynamics and work practices but also the craft itself. Navigators are forced to re-imagine where the craft is and where it is headed. They have had to revise both their orientation toward the machine and their understanding of their own expertise. Navigating through the MONTE software is not about upgrading in the colloquial sense, or translating inputs from one tool to another; rather, it literally requires bringing sets of abstract figures side by side and trying to grapple with the unknowns that are producing differences. Holding both figures simultaneously also calls forth the nonhuman nature of the software systems. Each software tool provides a form of knowing that cannot know the other (or ever be fully known by the maneuver analyst who uses its outputs to support a particular account of its calculations). Each reconfigures a world of the planetary system that calls the other into question. Simultaneously, the constructed logics, organizational processes, and shared understandings that figure a reality within this mission (on Earth) are brought into relief.

MONTE is forcing shifts in how the Mission operates as an organization and as a craft. This involves a re-materialization and reconfiguration of how the elements of space exploration interrelate, entwine, and act on each other as well as the opening of possibility and reconfiguration of space. This moment in the history of the Mission highlights how organizational shifts, moves to create umbrella organizational efficiency, and improvements in software over time, do not engender a sort of linear progress. Rather, such shifts engender a substantively new world: new reconfigurations between what is known and what is assumed is possible; and new movements, new logics, and new organizational processes that are intrinsically connected to the material, technological, and physical world. The organization, the software, and the craft are in no way inseparable and the attempted change in navigational software reveals the ways in which each is constituted by the other, and thus becomes re-constituted, or reconfigured, when one shifts.

Example Two: Accounting for material breakdown

The goal of the Mission is to use the craft to explore, bring home, and create new knowledge about outer space. To do so, the team produces "sequences" of commands to collect data in the planetary system through a process that begins with science objectives and ends with commands that can be executed safely by the spacecraft. One of the key moments in this process is when the Attitude and Articulation Control Systems (AACS) team works with the Science Planning and Sequencing Team (SPST) to translate commands for collecting data into commands that are "flight ready."

But what is "flight ready"? The craft has been in orbit for almost seven years and is dependent on "nuts and bolts" that are over twenty years old (building began in 1990). When it was built, engineers designed the spacecraft according to a set of requirements and assumptions about preserving longevity. As such, they built in parameters assumed to keep the spacecraft operating safely. However, when one of these parameters is violated in space neither the cause nor the effect of this violation is immediately available to those on the ground.

An example of how such alarms might serve to reconfigure the materiality of the machine itself and affect how the organization operates emerged when a spacecraft engineer noticed spikes in the speed of one of the reaction wheels that is used to point and articulate the spacecraft. The reaction wheels allow the scientific data instruments mounted to the body of the craft to be pointed at targets in space by rotating the spacecraft. For example, in order for one of its cameras to point at and capture an image of a particular moon, the spacecraft must rotate in space. It does this through three reaction wheels, placed orthogonally at the base of the craft, such that each wheel can carry angular momentum along the multiple axes around which the spacecraft rotates. The pointing of the spacecraft is based on years' worth of negotiations about which scientific instrument will collect data where and when in the tour.

Engineers expected a certain amount of drag would be imparted to the reaction wheels as they encountered external forces such as debris, atmospheric elements on one of the planet's moons, or even solar flares. The spacecraft was therefore designed to overcome this drag by commanding the wheels to spin at higher rates. At the beginning of the mission the spacecraft office placed limits on how much force could be applied to overcome different drag forces. However, within the first half of the mission they came to trust the estimates more and more and gave the flight software "full torque authority" to command the wheel speeds. Over time, however, the spacecraft office started to see unexpected spikes in drag on the wheels (as revealed by unusual tachometer feedback). And in 2001-2002 the team tasked with attitude control began to receive input from the craft that there was instability with wheel three of the instrument platform. By 2003 it was determined that wheel three was sufficiently damaged that it was turned off and replaced with the back-up wheel.

When wheels encounter drag as the spacecraft careens through the atmosphere of one of the planet's moons during a flyby engineers are able to use that data to estimate the atmospheric density and learn to conduct flybys with greater accuracy. Such familiarity allowed engineers to trust the tachometers and rule out external torque forces when spikes in drag suggested that the wheels might be deteriorating. Understanding the actions, stressors, and potential breakdown of the wheels is a complex process rather than an obvious assessment. Engineers figure the "health" of the wheels via their understanding of the spacecraft and physical environment of the spacecraft (gravitational pull), and through a software tool that was created to help make these assessments.

Analysts use a software program called the Reaction Wheel Bias Optimization Tool (RBOT) to generate profiles of wheel speeds that will achieve the desired pointing of the spacecraft and rotation of scientific instruments while minimizing unsafe wheel speeds or other "consumables." Upon being given a potential sequence, analysts would run RBOT to assess wheel speeds perceived as 'safe' during the sequence and to determine how to return the wheels to 'safe' speeds before the next set of rotations. After instability with wheel three was discovered, the process of running and responding to RBOT feedback took on increased importance.

Given that this is a scientific mission, what happens when the wheels that are used to articulate the spacecraft, and so conduct science, weaken? The organization as a whole must take into account the reaction wheels, re-negotiate sequences, and begin to "see" the craft differently. In response to the data on drag spikes, the spacecraft office began to refine and enhance the RBOT tool to incorporate new knowledge about the wheel speeds (in communication with the original manufacturers and reaction wheel spin dynamics experts). Engineers recognized that some of the drag they were seeing was due to the wheels dwelling for long periods at low speeds (under 300 or 400 rpm) or crossing through zero (i.e. changing direction) frequently. In response they modified RBOT to optimize to these new constraints and include red-lined "keep out zones" in the outcome plots produced by the software tool. These refinements required those who directed the science agenda and those who attended to the physical health of the craft to communicate differently and re-orient their relations to each other, the craft, and their respective goals.

Movement of the wheels became highly constrained by the new RBOT parameters in ways that affected proposed sequences for capturing scientific data. As the organization began to increase the number of iterations of scientific observation pointing designs and RBOT solutions to find science "friendly to the wheels," the computational run time and effort to come up with and analyze alternative solutions began to exceed the time allotted in the schedule. AACS analysts began to run out of time. Already constrained by the performance of the wheels in space, they now found themselves constrained too by the performance of their own computers on Earth. They simply could not find solutions within the newly established wheel speed limitations that allowed science-pointing sequences to remain unchanged. The analysts asked scientists to prioritize their observation requests so that analysts could focus on finding solutions for the wheel constraints for those scientific measurements of highest priority.

However, this perspective from one side of the organization was incommensurate with the practices in place on the other side. The mission scientists, who are organized into distinct instrument teams with rights and responsibilities for collecting and using a single instrument's data organize in terms of segments rather than turns. These teams were perplexed by the request to "prioritize." Any observation that had made it into the plan for the segment was already top priority, or else it would not have survived the rigorous and multi-stage process of planning and negotiation across multiple science teams. Also, because each instrument conducts its own investigations, judging the priority between say, a particle physics experiment and a measurement to secure a geophysical model was seen as an unfair question of comparing apples and oranges. The scientists were now required to think about commands in terms of the RBOT simulator, whose principles were opaque to them. They therefore asked the planners to articulate how RBOT worked and provide tips and guidelines for "RBOT-friendly" pointing designs: a challenging task because their simulator judged designs holistically rather than distinct operations.

While the impetus of these shifts was a perception that a wheel was failing, this perception emerged from a software program designed to extrapolate from proposed actions and a desire to preserve a material object that was, literally, untouchable. Redesigning the RBOT software created a new reality that the organization, the people, and the scientific mission had to orient around. The question of planning the spacecraft's observations suddenly had to take new representations and perceptions of the spacecraft into account. The software simulator that represented potential wheel activity thereby reconfigured the spacecraft for its team on Earth. Data originating from the wheels of the spacecraft inserted a granularity of attention (spin by spin, rotations per minute) that came to matter to the entire mission and their ability to conduct science. But it also required confronting incommensurate sociomaterial relations available on each side of the organization, engineering and science. It is not a question of which way of planning, activity-by-activity or segment-by-segment, is inherently better – rather, each figures the spacecraft quite differently.

Prior to the perceived breakdown, designing sequences of pointing instruments had become routinized and partially automated. Being asked to "do" design again after years of copy and paste, then being asked to change designs to meet engineering guidelines – or face having science completely "deleted" or "killed" – was threatening, disorienting, and reorienting to scientists who had not previously noticed an aspect of the craft that was beyond the scope of their concerns. Such reorientations became apparent as people created a new vocabulary to account for the reconfigurations of work practice and began to align vocabularies that had evolved differently in different parts of the organization.

For example, science planning and analysis had different meanings for the word "segment" which had to first be noticed and then renegotiated when discussions about RBOT brought the discrepancy to light. Scientists divide up the tour into "segments" based on scientifically meaningful portions of the orbit (being close to a target or far away, etc) then they design scientific observations for those segments. Analysts think of "segments" in terms of turn by turn by turn. Any command that tells the spacecraft to turn starts up another "segment" in their language. Emergence of terms like "RBOT-friendly" and "like-minded science" also convey a reconfiguring of how people understood goals, actions, and perceived possibility through the lens of wheel rotations.

In essence, the breakdown of the wheel inspired a series of dynamic reconfigurations which simultaneously spanned, bridged, and re-constituted the material, physical, technological and social worlds of the mission. For, there is simply no way that the material reality of the craft and the social and organizational reality of the mission on the ground can be separated. The apparent randomness of alarms alerting engineers to the discrepancy of pre-designed parameters set to measure craft health undercut any implicit assumption that the social and material respond to each other in a linear fashion. And the social and organizational reconfigurations that emerged as a consequence of perceived material breakdown reveal how, within the processes of figuring, the material and social constitute each other.

Example Three: Relying on individual modifications

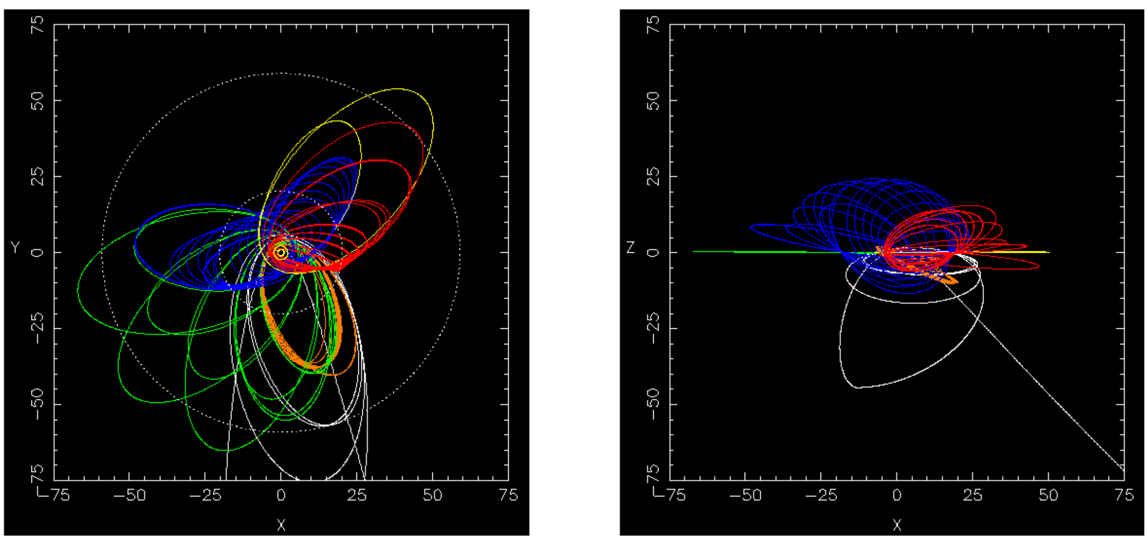
While there is a great deal of mobility across projects at the laboratory, many employees have dedicated a lengthy portion of their career to one mission. With long careers and cautious technological growth and upgrades, the bulk of work practices, organizational processes, and software-coded procedures and routines have evolved gradually at different levels of the mission and over multiple decades.

Software categorized as critical to the mission (categories A, B, and C denoting different levels of criticality) goes through a rigorous review process. At the same time, many pieces of software are developed by individuals. These small scripts that improve the ease or quality of work (stitching together smaller routines or automating everyday tasks) are called "category D" software. By definition "category D" software are small programs developed for personal use that one can "live without” if for some reason they are rendered non-functional due to other updates. Over many decades of mission work, however, these scripts have become pervasive; numbering in the thousands and becoming embedded in work routines as they were shared informally amongst co-workers. In the midst of major recent downsizing the MSS team was in the process of trying to recapture some of these unknowns (unknown software and unknown links between different ways of working) and working to actively inventory category D software.

The Tour Atlas is one of the more noteworthy of these organic software tools “home grown” over time by mission employees and reconfiguring the mission in unexpected ways. The Tour Atlas, a series of html pages with images of orbit plots (see Figure 1 below) and lists of events. It is the result of bits and pieces written by different people over the years, generated through a collection of programs and scripts written in various computer languages – an ad hoc software resource.

Figure 1: Tour Atlas sample orbital plots

T18-5 Nominal Mission Reference Trajectories



The Tour Atlas’ most recent contributor, Jim was a tour analyst for the mission who contributed to, synthesized, and automated the Atlas as a way to help the scientists explore the orbital trajectory. Scientists had charts given to them from the mission that showed the duration of time in different angles to the ring plane. Such charts helped illuminate large-scale opportunities for data gathering. But, in order to discover the precise timing of different kinds of events (like when a moon passes across the body of the planet), or particular geometries (such as the kind of mapping of the ground surface of a moon you could get from a particular flyby) scientists would call up Jim and talk through their particular needs with him.

Jim’s Tour Atlas became a kind of record of these requests and a way to make them more generally available. He created personalized software tools to help him plumb the data set of possible events, positions, and geometries in the tour, and then generated pages that others could look to like an almanac or atlas. Essentially, Jim created a collection of different techniques for dipping into the data set and creating tailored outputs like lists of events, plots of orbits, maps of ground tracks. He then splashed these outputs up onto an html website that came to be known as "the Atlas."

According to Jim, "the Tour Atlas is a series of shell scripts, perl scripts, FORTRAN programs, C programs, that link all these things together that allow us to generate those [plots] on the fly." The key idea here is "on the fly," which has a double meaning. On the one hand, the Tour Atlas was generated by Jim, often in response to particular requests with a very quick turnaround. On the other, the Tour Atlas is also generated while the spacecraft is flying and hence time is of the essence to make decisions about which trajectory should be selected or which observations will be designed. The Tour Atlas provided a rendering of trajectory data such that it created a new form of visibility and, as such, changed how scientists could engage with the craft and retrieve data from it.

The software behind the Tour Atlas, was by definition Category D software, because it was written and used solely by Jim, who could generate new html pages on the fly which were in turn a resource to others on the mission. However as an encapsulation of Jim's personal expertise and professional vision into the trajectory data set, the Tour Atlas made the trajectory knowable to the organization in new ways. Jim's agility in dipping into the vast database provided a way of continually reconfiguring the trajectory – literally putting abstract figures together – and created a form of knowledge and way of seeing the tour that the organization came to rely upon.

However, as part of the transition to the current phase of the mission, Jim was transferred to a new project. Before leaving, he was given the task of handing off the tool to software developers. The request to leave the Tour Atlas "workable" required that Jim port it over to a shared repository, translate procedures for using it into formal techniques, and document the current outputs in such a way that others could build the software, run it, and maintain it. This process of taking an organic on-the-fly piece of software and bringing it into the space of managed software development creates interesting after-effects for the organization. Ingesting the software into the organization's disciplined software space proved to be no easy task. After Jim's departure one software developer was asked to continue his detective work to understand how the Tour Atlas runs – without any need to know what purpose it served – and a science planner was asked to articulate the purposes it served to the organization.

This example highlights how an organization might only come to know what it knows and doesn't know at moments of transition and hand-off. Jim's departure from the mission became more than a simple hand-off of software – it revealed a reconfiguration of a set of relationships between code, people, and expertise as they sorted out how to maintain a workable set of software tools. Initial attempts to move the set of software programs and scripts from his account to another account "broke" the software. It became clear that the Tour Atlas had parts that were automated and other parts that were held together by Jim's know-how as he would take pieces of the software that weren't working and run them by hand on the side. As current team members worked to troubleshoot the software and get it running again, they could not turn to Jim to help recover knowledge about how the code worked.

Thus, Jim's departure revealed different ideas of what counts as "working" software. Software that "works" enough for its writer/user to get the job done appears to no longer work when the relationship between tool and use becomes formalized. Part of the work of ingesting the software into the organization was not only getting its pieces to cooperate but also to cleave the roles inhabited by

Jim. The result of the Tour Atlas hand-off was a recognition that software is not an entity into itself – it is not only important what the software does but how it serves to translate between the tool and its use. Software is, in effect, not identical to the code that runs on machines. It is also a set of relationships.

One of the challenges of downsizing in any organization is the loss of expertise and knowledge associated with particular personnel. The Mission wants to avoid "single point failures" where any single point in the process or a specific individual contains knowledge that, if lost, could result in failure. While personnel loss is captured as a form of generally understood risk, the link between people and the knowledge embedded into software is not well understood or part of organizational logics. Software and databases are seen as a kind of embedded form of knowledge, like a book in a library, available to be picked up by anyone within the organization at any time. Such tools are expected to exist and perform (especially automated software) independently of any individual and code is considered knowledge that the organization already has as a resource. But there is always the potential for obfuscation.

With the Tour Atlas the organization began to understand the extent of what was lost to the their body of knowledge and memory with the loss of personnel. Without Jim's agility in manipulating and understanding the database the Mission lost knowledge that had become both taken for granted and assumed to be necessary. In essence, the Tour Atlas (and Jim) took information available to everyone via the database and reconfigured it such that it became actionable. The re-materializing of the information into sets of figures on html pages created a space of knowing that influenced action. Jim, in his own way, was participating in reconfiguring the planetary system and creating a practical vision that became integrated into organizational negotiations of resources.

This type of reconfiguration in the face of software knowledge loss is not unique to the Tour Atlas. It is emblematic of the ways that software becomes entangled in sociomaterial assemblages, acting in ways that appear independent but are forever embedded in the work of those who have written and used the tools. For example moving the program out of Jim's home directory caused bad links in the scripts and they discovered that he had been using personal naming conventions that were difficult to interpret as they tried to reassemble the software. From this state of affairs, one could venture that Jim's departure from the mission reconfigured both current knowledge about the tour and practical knowledge about how to mine the database in complex ways. Jim's engagement with the Tour Atlas calls attention to the ways in which social, material, technical and physical reconfigurations can be called into being through informal and personal relations. Again, the ways in which sociomaterial relations shift, dance, and reconfigure each other are clear in the example of Jim and the Tour Atlas.

Taken together, the organizational request to "upgrade" navigation software, a shared perception that rotation wheels were wearing out, and Jim's tinkerings with the tour database illustrate emic moments of sociomaterial shift in which material, social, physical, technical and organizational realities reconfigure each other in constitutive ways. These examples provide illustrations of idiosyncratic and asymmetric shifting between action and reaction, perception and reality, agency and action. They highlight the ways in which moments of sociomaterial reconfiguring can emerge from innumerable sources including organizational mandate, material breakdown, or micro social relations. Further, they call attention to the ongoing reconfigurations that shape and constitute what is called into being as reality, possibilities for action, and scope of knowledge.

Discussion

Through the lens of these empirical examples we are able to highlight how dynamic reconfigurations happen and suggest the ways in which social and material considerations are brought to the fore and reconfigure each other in indissoluble ways. The contributions of this endeavor are thus twofold: we provide grounded descriptions of the asymmetric, dynamic, and co-constitutive relations that can be considered 'sociomaterial;' and we add to the methodological toolkit of scholars attempting to engage with this perspective through the language of *dynamic reconfiguration*. The theoretical value of this work lies in our ability to illustrate how of how the bounded categories of the social and the material are co-constituted and called into being in response to various triggers, asymmetric influences, figures (e.g. organizational charts, threshold marks) and figuring processes (e.g. enacted routines, software). Further, we show how such social and material considerations are mobilized, become relevant, and rendered invisible in the various processes of dynamic reconfiguration. In illustrating these relations we contribute an empirical presentation of sociomateriality that honors the entangled, emergent, and ambiguous nature of categories such as 'social' and 'material.' From a practical perspective this work suggests that the language of *dynamic reconfiguration* provides a linguistic pathway for future scholarship. Specifically, future studies on information systems and organizations would profit from taking into account how the various objects of analysis (e.g. information systems, specific tools, organizational routines, occupational functions) are being configured and reconfigured by each other in unexpected, nonlinear, and constitutive ways.

Situating dynamic reconfiguration

The very aspects of the Mission that propelled our interest in the manifestations of sociomateriality in this organization also serve as a counterpoint to implicit considerations that underwrite much of the recent interest in sociomateriality in organizations. We find that although current empirical studies are rich, evocative, and do much to further a perspective that takes social and material influences seriously, language often falls short and is unable to portray a mutually constitutive relationship with precision and dynamism. This has been the thrust of arguments recently criticizing the sociomaterial lens (Kautz et al. 2013; Leonardi 2013; Mutch 2013).

Empirical treatments of sociomateriality can make implicit commitments to the social/material relationship that constrain our ability to investigate how humans and machines represent, understand, and call into being the social and technological practices of each other. As noted in the introduction, treatments of sociomateriality are often focused on distinguishing between social and material domains; assigning agency, understanding how they become interwoven, and deconstructing the nature of the relations between them. Looking at the body of empirical papers that self-label their perspective as 'sociomatieral' we find a variety of perspectives that, in one way or another, subtly undercut a perspective on sociomaterial relations as mutually constitutive, asymmetric, and entangled in nonlinear ways. For the sake of analytical delineation, we have developed labels for these types of implicit commitments -- *separation*, *symmetry*, or *shaping*.

Separation: Sociomaterial scholarship that takes a *separation* perspective on social and material intertwining attends to the fact that materiality influences how humans understand their world, engage with technologies, and organize around, and in terms of, the tools at their disposal (Barley et al. 2011; Johri 2011; Rose et al. 2005). However, these works tend to focus on the ways in which material and human agencies interact without fully embracing a relationship of co-constitution or mutual shaping. While self labeling as 'sociomaterial,' and invoking language that does not give priority to social or material, these papers have an orientation that aligns with Orlikowski and Scott's definition of the research stream of 'mutually dependent ensembles (Orlikowski & Scott 2008 p. 446).

However, these studies do not fully account for the ways in which human perceptions of the material world shape possible lines of action or how material circumstances simultaneously invoke and mold social agency. For example, in his analysis of the work practices of software developers Johri uses language such as "the nested relationship between workers' use of information technology and their social practices" (Johri 2011 p.955). This language suggests a bifurcated and independent relationship between actions related to the use of technology and social dynamics. Likewise, in describing the effects of perceived email overload Barley, Meyerson and Grodal consider the agency of material technologies as a factor in human experience but describe sociomaterial accounts of a technology's use as, "accounts that weave together rather than segregate social, symbolic, and material realities" (Barley et al. 2011 pp.887-888). Neither of these papers articulate how material aspects of the technologies are called into being through social dynamics, or how the organization and shift in its relation to the logic, processes, or material properties of the technologies.

Somewhat ironically, the billion kilometers between the spacecraft and the laboratory undercut rather than reinforce the notion of a socio-material *separation*. This is true for three reasons. The first is that material manifestations of the craft (in the forms of documents and their processes, simulations and their visualizations, software systems and their commitments, blackboards and their accountabilities, and spaces and their politics) are a practical and ongoing accomplishment achieved within a web of sociomaterial reconfigurations. The second is that the material limitations posed by physical properties of space (such as the speed of light), hardware (inevitable breakdown of material substances) and organizational structures (division of labor into mechanical and infrastructural subsystems) remain critical elements of the everyday experience of the team. Finally, the operations of the spacecraft in the work of the space scientist and engineers are clearly social as much as material in their origins, being the products of intricate technical and organizational processes that manifest a material object that is materially out of reach. So, no simple separation between the domains of the social and the material is sustainable here.

Symmetry: While some empirical examinations of sociomaterial relations embrace more of a co-constitutive perspective on the relationship between social and material considerations, they do so in a way that suggests a forward processional of human/machine interaction with each 'side' influencing the other in lock step that implies *symmetrical* relations (Østerlie et al. 2012; Volkoff et al. 2007). For example, Volkoff and colleagues present an implicitly linear process of technological implementation that becomes a "midrange process theory of organizational change" in which technologically mediated change is presented as,

A set of alternating cycles where the ostensive and the material aspects become mostly aligned during design and construction, enabling significant changes to organizational elements over short periods of time, followed by periods where the performative and ostensive aspects interact, but are constrained by the material aspect, leading to new interactions between the material and the ostensive (Volkoff et al. 2007 p. 845).

Such an endeavor is focused on a universal model of change and therefore does not engage with the ways in which technologically mediated change may be, in fact, an unpredictable, shifting, and emergent experience that is subject to the open-endedness of sociomaterial phenomena. Similarly, while Østerlie, Almklov, and Hepsø take pains to note that "materiality plays an integral part in creating, not simply representing, the materiality of the physical world" (Østerlie et al. 2012 p. 87) they also describe their theory on ways of knowing in petroleum production as "elaborating how knowing emerges from the *patterned interactions* between material phenomena, material arrangements for knowing about these phenomena, and knowledge practices." (emphasis added) (IBID p. 87). This language tilts toward an understanding of knowing as something that emerges as the result of a lock-step interaction.

Such *symmetry*, as a foundational assumption, is called into question in our resaerch by the shifting web among different elements – people, organizations, the spacecraft and its instruments, the computer systems by which these are all coordinated, and more. Each of these elements in the sociomaterial assemblage appears to take turns (in no particular order) in instantiating shifts in relations. One does not influence the other in a predictable volley of reconfigurations. In fact, the stability that is required to sustain such a symmetric account of sociomaterial relations is notable by its absence, even in a project of such long duration. While there are striking analogues between arrangements "on the ground" and arrangements "in orbit" – divisions of organizational labor coordinated with the structure of the spacecraft and its various instruments, for example, or analogies between reaction wheels and RBOT as components of the spacecraft's function and operation – the coordination of the project as a sociomaterial whole is a dynamic tangle rather than a balance of symmetric forces.

Shaping: Finally, some research frames social/material relations in a manner that privileges (explicitly or otherwise) the ways in which human agency can *shape* material properties with unidirectional force (Johri 2011; Leonardi 2011; Doolan 2003). While these papers point to material properties as contributing to how people perceive and engage with the material world, they slant their analysis toward incidences in which humans are able to purposely shift or alter materiality to suit explicit goals or push forward a political agenda. Johri, for example uses language emphasizing that, "team members used the resources at hand to the best of their ability. They stretched the boundaries of what was possible with the resources they had at hand" (Johri 2011 p.962). This statement suggests the unidirectional influence of humans on and over technology.

Leonardi goes beyond this implicit assumption and takes as an explicit premise that, "Today, workers have many opportunities to make material changes to the technologies with which they work" (Leonardi 2011 p.148) and goes on to emphasize that technology is, "embedded in a context where people can have it modified to fit their needs in relatively short order. In many modern organizations it may be as easy for people to change the material makeup of a technology, and hence its material agency, as it is for them to change existing routines" (Leonardi 2011 pp.148-149). By emphasizing particular moments where humans can actively modify the underlying code in a computer simulation technology, Leonardi is taking a particular stance about the relationship between human agency as shaping (rather than simultaneously being shaped by) material and technological considerations. These papers privilege the perspective that humans, or certain humans, are able to purposively reconfigure and re-work the entangled sociomaterial environment in order to reflect their choices, wills and desires.

In presenting the Mission as a dynamic tangle we present an alternative to this perspective by calling attention to the forever temporary and fluctuating agencies at play in the sociomaterial assemblage. We have focused here on reconfigurations as a central metaphor, but, in the spirit of these fluctuating agencies, our reading of reconfiguration is not simply as a moment of responsive change, but rather as an ongoing and continual – an endless process of world-making through representational forms (figuration), arising in concert and in conversation with other sociomaterial elements (*con*-figuration), over and over in dynamic efforts to achieve local stabilization (*re*-configuration). In showing the ways that material, physical, technological, organizational and social elements are tied together in a relation of ongoing reconfiguration we call attention to ways in which there can be no simply unidirectional *shaping* by humans on their environments, nor by the environments on social processes or arrangements. Rather, mutual reconfiguration and parallel co-constitution are the order of the day, through dynamic shifts of concern amongst many different elements. To frame this in the perspective of shaping would require both a stability and a directedness that we do not find at work in our data.

Again, we applaud empirical accounts that attend to the ways in which social and material actions are implicated in and through each other. We contribute to this scholarship by invigorating the lens of *dynamic reconfiguration* and, in so doing, attending to the dynamic, asymmetric and shifting figurations of the relationship between social and material realms – and all that such categories invoke. Taking the ongoing process of figuring as a starting point, we move beyond the implicit assumptions of separation, symmetry, and shaping to examine how the actions of individuals, social norms, institutional structures, and abstract figures act to dynamically and asymmetrically reconfigure each other and, in so doing, constitute, articulate and instantiate the realities of organizational life.

As is unavoidable in all research of this type, our study is limited by a focus on a single empirical domain. The unique properties of The Mission, its longevity, intimacy with physical properties of earth and space, unwavering orientation toward the goal of using one piece of hardware to collect data, and the resulting inability to stay "up to date" with software products and upgrades, limits our ability to directly transfer insights garnered in this environment into other organizations. Future research is required to see how fast paced environments with regular shits in staff, goals, and tools would benefit from a perspective of dynamic reconfiguration. However, our focus on unexpected shifts and asymmetric relations lends itself to analysis of environments that could be considered more 'dynamic' than The Mission.

In fact, the rarified environment of The Mission serves to illuminate these considerations in important ways. While all organizations must confront and negotiate physical and material environments, employees at the laboratory have a particular orientation to the constitutive power and unpredictability of the physical world. This focus on, and respect for, the vicissitudes of physical constraints suggests ongoing reliance and negotiation with material forces that exist, but can be masked in traditional organizations – both as part of the practical accomplishment of organizational functioning and in scholarly accounts of information systems and organizational life. Thus, this treatment serves as a reminder to those engaging with software, hardware, and technological systems across organizations to attend to the ways in which organizational structures, physical processes, routines and relationships reconfigure each other in deeply constitutive ways.

However, our motives for highlighting this mission also concern what it does not have. The unique circumstances of this organizational environment call into relief the ways in which information technologies are active participants in sociomaterial reconfigurations. For, while the mission is thoroughly concerned with the manipulation of a physical object – a spacecraft – it has no immediate physical access to that object. The spacecraft is over a billion kilometers from Earth; it can be apprehended and understood only through telemetry, simulation, and mathematical models. The spacecraft is not accessible to hand or eye, even through the mediation of advanced instruments. It is material in its physical forms; it is immaterial in the disappearance of that physical form from immediate view; and it is rematerialized as images on screens, as figures in spreadsheets, as mockups and models and proxy objects (such as the coffee mug that many project members have on their desks displaying the various scientific instruments as a reminder of the relevant physical layout of the spacecraft).

Even more interesting is the variety of re-materializations that characterize how different groups interact with and imagine the craft (science planners have a mug that visualizes the instruments themselves while the AACS engineers have a mug with the image of a toilet paper roll with two paper clips stuck through it to create the three axes about which the craft can rotate). Thus, even in the details of the mugs we see different practices of figuring across teams. This example serves as a reminder that the ways in which humans and machines figure each other is not only asymmetric (organizations do not reconfigure hardware and software in the same ways that these entities affect organizations) neither is figuring uniform across organizations themselves.

Conclusion

This paper suggests that sociomaterial accounts of organizations can benefit from a close examination of *dynamic reconfiguration*. On the one hand, figures are mutually negotiated, and forever temporary, stabilities of sociomaterial assemblages. As such the act of creating abstract figures suggests a process of reconfiguration – or figuring with, figuring in terms of, and figuring over and over again. This account takes one perspective on figures as constitutive, but it does so, crucially, by taking "figure" as a verb. Ongoing acts of documenting, imaging, and imagining the world – graphically, mathematically, numerically, digitally, physically, organizationally – engender reality through dynamic reconfiguration between and across sociomaterial phenomena.

On the other hand, "figure" is also a noun. As material objects themselves they are also productive of discursive reality. The navigational algorithms and the curves that they produce, the mathematical equations that describe drag, the implementation of particular kinds of models in software conjure particular kinds of worlds into being, and their materialities – from the ability of some figures to move easily in the world, to the problems of working with simulations that need hours or days to compute – shape these worlds. While the productive qualities of particular abstract figures – artifacts, models, schemes, and stereotypes – are not the focus of this paper, we suggest that future work in organizations and information systems could explore in more depth the particular forms that software (and other figuring technologies) takes and the ways in which these forms – graphical and lexical expressions, columns of numbers, or records in a relational database etc. – constitute and shape the sociomaterial. For, the particular form, quality, and presentation of a figure shapes what can be easily asked of it, the kinds of manipulations and analyses it supports, and how it can be used to understand the world.

Finally, one particular form of figures – that of numerical codes and mathematical descriptions – play a central role here, but, as perhaps the MONTE example demonstrates most clearly, by no means a univocal one. Indeed, that example highlights most particularly the work that arises to manage the ambiguity amongst mathematical and numerical accounts. Here we find parallel numerical accounts that, each consistent in their own worlds, must somehow be made to work together. Thus, through this example we can point to the many different figurings and sociomaterialities at work in the organizational tangle that we have described. Similarly, the issue is not how the immaterialities of RBOT and the realities of reaction wheels can be understood to correspond, but rather how RBOT's material instantiations and an imagined spacecraft come together as a sociomaterial whole.

We have turned to ethnographic materials to focus attention on how to approach sociomaterial relations empirically. As such, we provide an example of how to embrace a dynamic and constitutive view of sociomaterial relations through grounded data. But our contribution is not simply an empirical one. Conceptually, the turn to figuring is, in the small, an attempt to revisit and re-examine the notion of reconfiguration that arises when information technologies are invoked as part of a story of shifts in organizational practice (as in, "the new ERP system reconfigured the organization"). In the large, *dynamic reconfiguration* offers a route towards reframing both the nature of materialities of organizational practice and the role of information and information technologies in the emergence of sociomaterial assemblages.

A more typical methodological contribution to information systems research would make the claim that applying the suggested method would lead to 'objectively' better outcomes (along some pre-defined metric) than prior methods. However, the ontological perspective implied in sociomaterial accounts undercuts such an endeavor – suggesting, in fact, that such tools of measurement reconfigure findings through attempts to sediment and assess outcomes. As such, the attempts to fix and measure methodological contributions calls into being certain aspects of the sociomaterial tangle and privilege certain representational figures as illustrating a primary way of knowing. The limitations of this project thus lie in our inability to call upon prior metrics for assessing the methodological contribution suggested here.

Instead, we argue that the methodological contribution of the lens of *dynamic reconfiguration* lies in how it provides analytical traction into phenomena that are difficult to articulate. It provides us with a language and a platform for studying sociomateriality in organizational life and informational systems – and the constitutively entangled relations between them. This analysis suggests that the relationships between the various dimensions of any sociomaterial analysis are forever in action, and interaction, and provides some insight into how to empirically describe and embrace this dynamic in information systems research.

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