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Janet Vertesi[1]

Abstract

Understanding contemporary environments in the laboratory and elsewhere requires grappling conceptually with multiple, coexisting, nonconforming infrastructures which actors engage at the same time. In this article, I develop the analytical vocabulary of "seams" for studying heterogeneous, multi-infrastructural environments. Drawing upon six years of ethnographic fieldwork with two distributed science teams, as well as studies in Ubiquitous Computing, I examine overlaps among infrastructures and how actors work creatively with and across their seams. Rather than suggesting that actors are hemmed in or incapacitated by multiple infrastructural commitments, inclusions, and exclusions, I show instead how they work artfully to align them in ways concordant with membership and how this produces both consequences for their work and opportunities for analysis.

Keywords

methodologies, heterogeneity, infrastructures

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Figure 1. Computer workstation at Deep Space Network (DSN) ground station. Note the American wall plug socket and European converter, the lock and stickers as markers of security. Author's photo.

> "Often it is not so much a matter of living in a single mode of ordering or of 'choosing' between them. Rather it is that we find ourselves where these modes join together. Somewhere in the interferences something crucial happens . . . "
>
> Mol and Law (2002, 11)

Introduction

A computer sits in a corner, sandwiched between a desk and a wall (Figure 1). It is marked with a sticker and a lock to identify it as a US Government machine and is plugged into the wall in what appears to be a relatively unassuming way. Unassuming, that is, until you realize that this photograph was taken 30 km outside of Madrid, Spain, at the Deep Space Network (DSN) telecommunications station.

The three-pronged wall sockets are suddenly, vividly, out of place. Supporting their operation is an on-site generator that steps down the power from the European 240 V grid to wire the entire premises to the American 110 V standard. This includes the six satellite dishes that the facility operates, ranging from sixty to eighty meters across, which listen round the clock for data transmissions from the National Aeronautics and Space

Administration's (NASA's) distant spacecraft to Earth.[1] Since only American three-pronged outlets are installed in the building, the European power strip atop the machine reveals a creative local solution for the lamps, cell phones, and other devices that belong to the Spanish nationals who work at the facility.

Much work in technoscience studies has examined the role of infrastructure in knowledge production and practice, demonstrating how each infrastructure presents its own politics, standards, ways of knowing, ontologies, temporal rhythms, and interactional possibilities (Bowker 1994; Star 1999; Bowker and Star 1999; Edwards 2010; Ribes and Lee 2010; Jackson et al. 2011; Millerand et al. 2013). Yet as this image reminds us, we rarely use such systems in isolation.[2] Sociotechnical systems overlap, often messily. Here, American engineers implement a US-compliant electrical network amid the Spanish grid, and Spanish engineers deploy off-the-shelf converters to plug in their locally bought lamps and cell phones. Other nonconforming systems pervade this laboratory in the move toward e-Science (Hine 2002; Olson, Bos, and Zimmerman 2008; Wouters et al. 2013). Scientists use competing software suites to analyze distinct types of data, spending hours converting file formats and crunching statistical data sets across a variety of platforms. Labmates communicate by e-mail, Facebook, and Short Message Service (SMS) about their ongoing experiments, while maintaining digital ties that appresent (Knorr-Cetina and Bruegger 2002; see also Beaulieu 2010) remote colleagues, affiliates, and competitors. Teleconferenced meetings are a commonplace, with lab participants working from home, coffee shops, or while in transit. As each infrastructure presents its own inclusions and exclusions, interactions in multi-infrastructural space[3] present implications for what work is done and how it gets done.

In this article, I draw upon empirical snapshots from over six years of ethnographic fieldwork with two large-scale distributed planetary science teams, to develop a vocabulary for studying environments in which many layers of infrastructure (both physical infrastructures such as power grids and digital ones such as teleconference systems, specialist software, and commercial systems such as Facebook) are copresent alongside the ethnographer and her participants. I seek to draw our attention to this very multiplicity: the overlaps among infrastructures and how actors work creatively with and across their seams. Rather than suggesting that actors are hemmed in or incapacitated by multiple infrastructural commitments (Star 1991), I show how actors work artfully to align them in ways concordant with membership, and how this produces both consequences for their work and opportunities for analysis.

Multiplicity and Seams

Confronting multiple infrastructures puts us at the same time on familiar and unfamiliar ground. Existing analytical tools confront novel limitations. Infrastructural inversion (Bowker 1994) is a logical starting point for any infrastructural analysis. But with so many sociotechnical systems at play, it can be unclear which to invert, and which are most important for enabling and constraining action. Boundary objects, translation, and trading zones are also essential tools for examining negotiation across infrastructural environments (Star and Griesemer 1989; Galison 1997; Gieryn 1999). But amid multiple categories, distinctions, and structures, boundaries become slippery and less straightforward to identify. The notion of "torque" (Bowker and Star 1999) is important for understanding how categories, inclusions, and exclusions work in practice, but in multi-infrastructural space the problem compounds. It might seem that with so many conflicting categories at play, actors are increasingly trapped and hemmed in or agency is curtailed. Yet experience suggests that not all are incapacitated.

The approach to heterogeneity and multiplicity suggested by John Law and by Annemarie Mol offers a potential way to address such problems. In their recent studies of the work of making complex objects singular, these scholars address the analytical management of multiple systems of ordering: what they call "complexity." The authors note that one factor of complexity is that "various orderings of similar objects, topics, fields, do not always reinforce the same simplicities or impose the same silences" (Mol and Law 2002, 7). Complexity therefore arises from the simultaneous presence of many orders. Law also reminds us that sociotechnical systems are heterogeneous in many ways: in their entangled social/material components; in their assemblage by a "heterogeneous engineer" into a networked, stable whole (Law 1987); and in their noncoherence. That is, the connections between constituent systems "aren't connections because they aren't coherent and they aren't joined up into something consistent. Except that they are nevertheless brought together . . . " (Law 2002, 106).

This notion of complexity gives us a system-level view, where we might examine the partial connections between constituent elements or the instantiations of their enactment. But what of action and interaction in this network? Certainly, infrastructures both enable and constrain members' action. But if action is infrastructured,[4] and infrastructures are multiple, then the challenge is not only to develop a conceptual vocabulary that describes this situation of infrastructural heterogeneity, but at the same time places our analytical focus squarely on actors and their practices at the local

level as they encounter and manipulate so many infrastructures in deployment.[5] In particular, I am interested in an approach to heterogeneity and complexity that places emphasis on how and where actors make connections and bring disparate elements together, framing heterogeneity as members' work.

This requires an addition to our analytical toolkit. Our vocabulary must accommodate heterogeneity, not only because of the combination of multiple users, actors, and system constraints but also because of the unique combinations of overlapping yet different categorical distinctions—what each system supports or excludes. It must consider the constraining nature of infrastructures at the same time as it observes how actors skillfully produce moments of alignment between and across systems: not fitting distinct pieces together into a stable whole, but *producing fleeting moments of alignment suited to particular tasks with materials ready-to-hand*. Rather than moving to the macro view of a meta-infrastructural analysis, it must hold our focus steady on the micro: actors' observable, reportable activities as they wrestle with many infrastructures' limitations and possibilities to bring them into moments of alignment. Finally, it must address a methodological concern in infrastructure studies: when the ethnographer is confronted with so many infrastructural systems in play in a field site, each of which contributes to action and interaction in a particular way, how can she locate "where the action is" (Goffman 1967; Dourish 2001)?

Seams and Seamfulness

To meet this need, I propose adopting some vocabulary from critical studies in Ubiquitous Computing (hereafter, Ubicomp): the language of *seams*. This discourse was first introduced by one of the field's founding members, Mark Weiser, who gave voice to a vision for the future of computation that hoped for the *seamless* integration of each device within social space and with other devices around it.[6] Weiser described this as, "the nonintrusive availability of computers throughout the physical environment, virtually, if not effectively, invisible to the user" (Weiser 1993, 71). Weiser's vision echoed many visions present in science fiction and other cultural forms, describing devices that would move off the desktop and into everyday spaces and objects, from our wristwatches to our walls. Weiser's vocabulary was also associated with a specific research and design agenda that aimed to produce sensors, wireless networks, and biometrics that could combine to produce a unified sense of digital space, *seamlessly* integrated with the world of human experience. The gaps between each system (the

systems' "seams") would be invisible to the user moving between, across, and within computationally enabled platforms, producing a "seamless" user experience. This language of seamlessness, invisibility, and non-intrusion has produced a range of device ecologies in the field of ubiquitous computing.

Recognizing seamlessness as a vision of a future not yet present, other designers in Ubicomp have explored the inverse of a seamless world: highlighting the seams between systems, instead of working toward their eradication. For example, a research group at the University of Glasgow chose to celebrate what they called the *seamfulness* of contemporary digital infrastructures (Chalmers and Galani 2004) by making infrastructural incompatibilities and limitations a central part of user experience. To illustrate this, they designed a mixed-reality treasure hunting game played by individuals with handheld devices. Players were required to search for open and closed wireless networks on the streets of Glasgow, harvesting virtual fruits among different networks to "feed" a shared virtual pet (Chalmers et al. 2005). As the user's play took place where infrastructures fail, end, exclude, or clash, the system made invisible digital infrastructures visible by surfacing and exploiting their *seams*: in this case, the gaps between wifi networks and cell phone coverage. Inspired in no small part by the work of Bowker, Star, and colleagues, this vision has also proven a useful point of departure for theory and design work in Ubiquitous Computing (cf. Dourish and Bell 2011).

Importing this language of *seams, seamlessness,* and *seamfulness* to STS draws attention to often-overlooked conceptual and empirical aspects of infrastructural work. The language of seams reminds us that infrastructures often collide: their seams are visible in their many edges, endings, and exclusions. Unlike the metaphor of the boundary, or even a sense of layering, the language of seams and seamfulness posits that each system lies in messy and even unarticulated local overlap with other systems. Rather than presenting stable nodes for assemblage, seams suggest that there are many possible ways to patch multiple systems together into local alignment.

In this way, multi-infrastructural work across heterogeneous systems becomes less a question of boundary work as it becomes a kind of ad hoc *patchwork*.[7] It is a sort of lay practice of heterogeneous engineering (Law 1987) that produces fleeting alignment or misalignment of infrastructures to accomplish local, mundane tasks. Situated among infrastructural seams, the analyst witnesses things come together, and apart, and together, and apart again. As actors work with and across infrastructural seams, they demonstrate familiarity, expertise, anxiety, and even playfulness. Thus, infrastructural alignment not only occurs on the mesa-scale of institutional

"synergizing" (Bietz, Lee, and Baumer 2010). Much is observable in moments where individuals bring these infrastructures together in locally accountable ways to produce either *seamless* or *seamful* multi-infrastructural action and interaction.

A benefit that this approach offers to the concept of complexity is the emphasis on actors' local practices, skill, and membership. The Spanish example is particularly illustrative. The tangle of cords behind this desk reveals actors' ad hoc efforts to translate or coordinate across multiple infrastructures. The coexisting infrastructures of American and Spanish power and computation are neither distinct, nor binary; we cannot even clearly identify one as layered atop the other, and while we can identify local coordination points we cannot necessarily see where one begins or ends. To speak of boundaries or translations between them would be to reify distinctions that are less distinct in practice, and to lose the sense of both infrastructural heterogeneity and the agency of actors engaged in its everyday management. But it is also precisely *here*, sandwiched between the desk and the wall, that we catch a glimpse the technopolitics of the "entangled geographies" that produce this particular global network of American state power (cf. Oldenziel 2011). We do not have to zoom out to international agreements or global maps: it is present in our attention to how actors work locally and creatively to reconcile distinct infrastructures, each with their own systematic categories, alignments, and misalignments. Such work constructs a shared, ephemeral space across multiple seamful infrastructures, establishing at the same time both interactional ground and membership.

Infrastructural Alignment: Crafting Seamlessness

The case in Figure 1 presents a kind of archaeology of seams through the remaining jumbled artifacts that support interaction with (or despite) the different electrical grids. But seamful work applies equally to digital infrastructures. Here I turn to examples drawn from my ethnographic case study: work with two robotic spacecraft teams composed of scientists and engineers, located around the United States and Europe. This case is illustrative due to the continuous use of multiple, heterogeneous, seamful infrastructures to support collaborative work. Although sponsored by national space agencies, the teams' participants are located at different institutional centers including private and public universities and research laboratories across several Western nations. They therefore rely heavily on ready-to-hand digital systems in the course of their daily work. As these infrastructures

overlap, collide, and even break down, we witness how actors work artfully across infrastructural seams to patch together coherent interactions.

For example, one spacecraft team meets daily to discuss what their robot will do on another planet the next day. The meeting used to take place in person when funding levels were high: now it regularly takes place over a mishmash of teleconferencing systems, videoconferencing nodes, and file sharing sites. Three institutions share Polycom links, a basic videoconferencing kit of hardware and software that unites scientists across three states. Everybody else connects via a teleconference line, their connection proclaimed with a bleep and computerized announcement that disrupts conversation. Most call from their desks in other institutions, or from wherever they happen to find themselves that day. This could be a sunny backyard in California, where one scientist regularly phones in while wearing his bathrobe, laptop, and coffee in hand. Or it could be the hallway of a space science conference in Houston, where several team members once crouched around a Wi-Fi hotspot to maintain their individual Skype connections (thereby choking each others' bandwidth). At another moment, I witnessed a scientist in a busy conference session room, with only the blinking light of his Bluetooth earpiece indicating to those nearby him that he was copresent elsewhere. One scientist frequently called in from the road while dropping his children off at school for the day, while a German often missed dinner with his family to call from the office. Everyone knew about a particular "dead spot" which often affected a commuting scientist's ability to stay on the line: unavoidable due to his institution's contractual agreement with a local wireless carrier. A constant in the meeting was a video camera at a participating government laboratory site trained on three big screens at the front of the meeting room, broadcasting an image of the projected screen to a protected internet site for remote scientists to follow along; a second camera was trained on the room itself, where the empty chairs designated the "virtual" attendees (Figure 2). Throughout the meeting, participating scientists regularly traded e-mails, text messages, and Instant Messages, and when the Polycom system froze, everyone hung up and dialed in again on cue.

This shifting, heterogeneous, multi-infrastructural environment is how—and where—work gets done, decisions are made, and scientific questions communicated. Each infrastructure contributes its own inclusions and exclusions, fragilities and potential. However, it is not simply that work takes place among such complexity, in a system too large, unwieldy, and inconsistent to comprehend. Rather, we must remain attuned to how participating actors assemble this heterogeneous and partial system each time

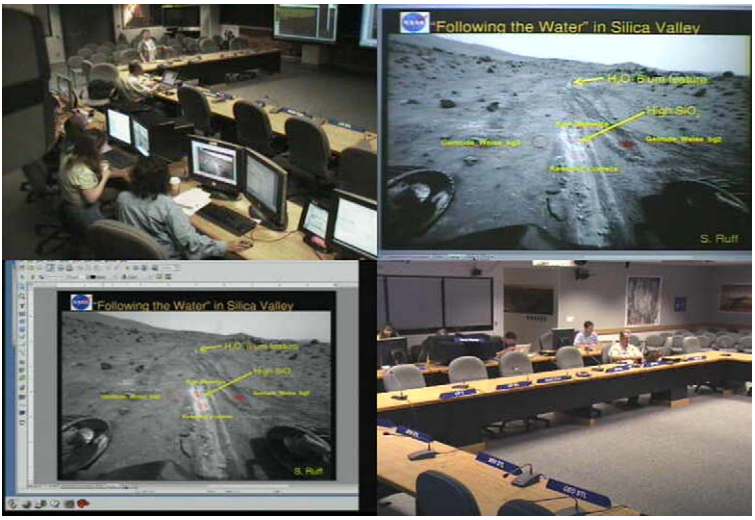

Figure 2. Webcam view of a planning meeting. Copresence is achieved by aligning multiple infrastructures including teleconference lines, video feed, networked software, and docushare sites. Empty seats at the table belong to "virtual" participants on the teleconference line. Author's photo.

from so many seamful components, like patchwork, using the infrastructural resources at their disposal.

For example, during my fieldwork with a second spacecraft team, I was sitting in a session at a large planetary science conference, when Tim, a mission team engineer, came in late and sat down next to me. As the speaker changed slides at the front of the room, Tim leaned over and whispered a question:

> Tim asks me what went on in the morning. I saw Alexa's status on Facebook that she was grateful to @planetgal for the [moon] session play-by-play. I look up @planetgal on Twitter and we [i.e. Tim and I] review her presentation summaries in 140 characters. Tim says, "ooh that's not good," when he sees her summary of Henry's talk. I'm wondering if it's not good because it's, say, contradicting [another scientist's] findings or something . . . but he says it's because the value Henry came up with for [the moon's] plume density is bad for the spacecraft if it's going [to fly] through the plume . . . He then picks up his iPhone and sends Henry an email asking him for his presentation so he can work with that value. (Fieldnotes, December 17, 2009)

Without leaving his seat, Tim aligned several distinct digital infrastructures—each with their own possibilities and limitations—to interact with Henry. The key players here were not just Tim, Henry, and myself; there was also Alexa, whom Tim didn't know, and @planetgal,[8] unknown to us both. Further, Facebook, Twitter, the laboratory e-mail server, and the iPhone each contribute their own peculiar possibilities and restrictions, producing and conforming to different kinds of social relations and interactions. Because of Facebook's reciprocal friendship architecture, I can see Alexa's Facebook status but Tim can't. Because of Twitter's open friendship architecture, we can both see @planetgal's Twitter feed despite neither of us knowing who she is. @planetgal can tweet session summaries because of conference Wi-Fi, but must distill complex science articles into only 140 characters to satisfy the Twitter infrastructure. Unlike a text message or a whisper, Henry's e-mail can be forwarded. Tim and Henry can interact from opposite sides of the room because of their synched contact lists on their company-provided computers and iPhones, and because while Tim's AT&T-locked iPhone 3G coverage does not extend to this room in the basement of the conference center, there is an open conference Wi-Fi network; and so on.

Which infrastructures Tim aligns, with their various inclusions and exclusions, are consequential for this interaction and for the mission. Within minutes, Tim has not only relayed Henry's calculations back to his team at the engineering facility; they have discussed (on e-mail, SMS, and teleconference) and narrowed down potential spacecraft maneuvers based on this new value for the plume. A few weeks later, the spacecraft flew past the moon to observe the plume—at a distance based on Henry's calculations.[9] Working across these infrastructural systems to produce a fleeting moment of alignment, Tim accomplished the goal of seamless communication with Henry.

The infrastructures at play here are neither stable nor routinized, nor singular. As multiple nonaligned systems of power, norms, ways of doing, standards, and identities, they are each negotiated, established, and reestablished through the work of alignment at the micro scale. When accomplished well, actors interweave the digital, optical, computational, and physical context of interaction so tightly that they are treated as copresent in practice. Indeed, the scientists I studied frequently recounted interactions that occurred via a phone conversation, an e-mail, a text message, and a Facebook wall post the same way ("he said," "she told me," or "I heard") without noting the medium.

That does not mean that analysts should ignore the medium too. After all, the material and mediated conditions under which exchanges take place

have implications for the continued production of power, knowledge, and value.[10] Such mediations not only enroll heterogeneous users and actors but also different categorical distinctions. These overlapping distinctions—that is, what the system supports and what it does not, who is left in and who is left out—produce a multi-infrastructural environment with many seams. Like David Stark's (2009) example of Hungarian factory workers who work under one organizational structure in the morning and another in the afternoon, interlocutors make strategic choices about which set of infrastructures, norms, and opportunities they will invoke in interaction. Unlike Stark's case, however, these multiple modalities are *simultaneously* available. Exactly how to align them "properly" takes not only skill but also members' knowledge of how to work across them in a locally accountable way. Thus, seamlessness cannot be assumed: it is produced and reproduced by actors in ways appropriate to local membership.

This suggests an implication for our understanding of copresence, which Beaulieu (2010) has articulated as a methodological shift in studying distributed organizations. That is: copresence takes *work*. It is established not through one but through multiple, heterogeneous infrastructures, each of which, as a unique system, presents possibilities but also limitations as actors combine them to craft a seamful interactional space. As a result, copresence (for both the ethnographer and other participants) is doubly partial. On one hand, there is no possible "best" experience of an interaction (something that we would expect given our attention to partial perspectives and anthropological reflexivity, cf. Haraway 1991; Strathern 1991); on the other, each individual's perspective is further limited and enabled by which systems they are using to produce their copresence, and how they align these systems with others. Telephoning in from the car produces a different meeting experience than connecting via videoconference, for example. Attention to how actors manage these seams in practice reveals how copresence is a multi-infrastructural achievement.[11]

Boundary Work: Online and Offline

Actors also construct boundaries in and through practices of seamful infrastructural alignment. An example is that of the apparently straightforward dichotomy of "online" and "offline."[12] It is tempting to assume that "online" interactions take place in digital environments, while "offline" interactions take place face-to- face. But empirical observation reveals *online* and *offline* to be emic terms that designate which activities, discussions, and individuals are part of the interaction, and which are not. For

example, following a face-to-face meeting discussion of a planetary aurora, a mission scientist closed the meeting with,

> We've surfaced a lot of discussion that various people have to have offline now I think. (October 25, 2010)

That is, despite meeting in person for a full day and adjourning the meeting to continue conversation over e-mail, the scientist described the group's upcoming activities as "offline." In another face-to-face group meeting, mission scientists discussed a potential spacecraft maneuver thus,

> I see these numbers but I'm not quite convinced . . . We should talk offline but I think there are ways to do this better . . . (June 7, 2010)

Requests for *offline* discussion do not only occur in face-to-face meetings. In another meeting when a scientist spoke up to protest procedures, the meeting Chair interrupted with "Sounds to me like this is sort of an internal [issue] to [your subgroup]." The response from the subgroup lead was "I agree, I agree, we should take it offline" (November 19, 2009). This prompted an immediate flurry of e-mails and phone calls, as the parties in question followed up "offline" with each other. The meeting was conducted by teleconference, and thus all parties who spoke were quite literally online (i.e., on the telephone line). Clearly, online and offline as actors' categories do not align with computer-mediated and noncomputer-mediated communications if one can have an *offline* conversation via e-mail and an *online* conversation face-to-face. But as categories, "online" and "offline" are drawn and redrawn to produce those alignments and distinctions that actors deem important to achieving local goals. Knowing when it is appropriate to make Facebook or SMS conversations "online" or e-mail exchanges "offline" is one of the infrastructural elements that is "learned as part of membership" (Star 1999). Thus, technological tools do not in and of themselves delineate online versus offline: actors do, and they do so to delineate distinct interactions, with distinct groups of participants.

This example also demonstrates how infrastructural seams differ from boundaries. Seams are resources that actors exploit to locally construct boundaries in and through their alignment practices. Mission scientists commonly use the mute button on their phones to rehearse responses or discuss options with a small group clustered around the telecon line, before pronouncing them in the group conversation.[13] Thus, they construct two

distinct interactional spheres—the *online* space of the telecon meeting and the *offline* space of the room—both articulated through the same equipment. They frequently forward or BCC'd e-mails from listserves to outsiders or individuals on the carbon copy list (CC) list to coordinate responses away from the main conversation, crafting the online space of the listserve and the offline space of the private e-mail. They also choose to phone in independently from their offices instead of from the main room with videoconference links, thus deploying the infrastructural resources and requirements of the telecon against those of a video feed or a shared meeting room to manage their visibility and audibility, to articulate different interactional spaces, and to conduct different kinds of work. Observing actors' creative use of infrastructural alignments and disjunctures can therefore reveal how they craft boundaries around and between different types of work, people, and interactions.

Caught at the Seams

Moments when actors fail to interweave their many systems successfully can be analytically useful for revealing otherwise invisible infrastructural components essential to the task at hand, and surfacing sociotechnical orders and tacit social relations to analytic view (Star 1999; Garfinkel 1967). As a simple example, at one mission's teleconferenced meeting, a scientist was poised to make a dramatic presentation of results that he hoped would sway the opinions of meeting participants toward supporting a particular observation. But as his colleagues loaded his slides for projection, he was dismayed to note that all his carefully crafted images were lost. He had dragged and dropped them into a Powerpoint file on his Mac, but in doing so the images were saved as .TIFF's and therefore did not translate to the PC projector. To his consternation, the conversation moved on without him. My field notes that day noted, "when you lose your images because of the MAC/PC thing . . . you can't make your point" (October 30, 2007).

Caught between multiple incompatible device ecologies, this scientist experienced what we might identify as "multi-infrastructural torque." The mismatch between Mac and PC infrastructural systems left him without the persuasive visual resources he had expected to use to make his case (Latour 1990; Shapin and Schaffer 1985). The scientist was therefore powerless to rally his colleagues due to his inability to align these infrastructures. This mundane miscoordination impacted mission operations, as the team did not implement his suggestion but proceeded with their investigation in a different direction. It impacted the scientist's status as (through no fault of his own) he appeared to be an incompetent user of his technology, and his voice

was lost to the discussion. It also reveals whose visuals it is important to wait for and whose are not.

When calls are dropped, Wi-Fi signals lost, polycoms reset, and devices don't talk to each other, there is analytical opportunity.[14] Such opportunity demonstrates the effortfulness of producing network centrality amid complexity: the precarious status of the heterogeneous engineer in bringing obstinate Wi-Fi nodes, polycom equipment, and cell phone towers together in even fleeting alignment.[15] But staying focused on what actors do with and across infrastructural seams reveals analytical opportunities for examining power structures in heterogeneous infrastructural environments. For what happens to those who drop out? How does one repair seamful copresence? Who does the repair work and what status do they have?[16] From whose (doubly partial) perspective does a hegemonic story of the interaction emerge?[17] What implications does this have for the team's work, for scientific findings, or for individual (or object) biographical trajectories within the organization? Attention to seamful interaction allows us to explore such questions in the context of heterogeneous infrastructural space.

Conclusions: Surfacing the Seams

The vocabulary of *seams* is a modest attempt to enable analysts to confront the heterogeneity and agency at play in multi-infrastructural sites, both within and outside of the locus of scientific practice. As a guiding metaphor, seams draw our attention to those places where multiple infrastructures are stitched together to achieve fleeting, nonstable, even ephemeral moments of alignment. This maintains a focus, popular in STS, on the edges, exclusions and inclusions inherent to particular infrastructures (Bowker and Star 1999), while at the same time seeking to understand those elements as they are constantly and creatively interwoven with other systems, invoking heterogeneity and complexity (Mol and Law 2002). Yet talk of seams, seamfulness, and seamlessness also surfaces actors' agency in the context of multi-infrastructural environments.[18] It brings our attention to actors' *work* to produce a shared experience of seamlessness, despite each infrastructure's unique and even conflicting distinctions. This reveals actors' local struggles and points of mastery with otherwise unwieldy infrastructures as they bring system properties in and out of alignment.

Such an approach offers several advantages to the study of contemporary sociotechnical systems. It maintains an interest in infrastructural work as practice, grounded in local members' work that is both situated within and produces local social orders. These practices are not divorced from politics:

after all, exactly which infrastructural seams are surfaced, aligned, and misaligned, as well as by whom, when and where, matters for actors' work. Further, emphasis on seamless and seamful interactions allows analysts to describe the role of commercial systems like Facebook or Twitter in our field sites alongside actors' communication practices and technical work, as consequential to technoscience. It simultaneously discourages a priori distinctions between "the virtual" and "the real," seeking out instead how various systems are locally intertwined and socially circumscribed, as well as how actors patch infrastructural elements together to produce local boundaries. Finally, examining how such systems are intertwined and circumscribed reveals fleeting moments of actors' creativity, expertise, and even disappointment that are essential to their work.

Ultimately, attention to infrastructural seams in their local, heterogeneous alignment maintains the conceptual commitment to surfacing the invisible work of infrastructures, while at the same time remaining committed to situated action, partiality, heterogeneity, and a grounded empirical approach. It focuses not on connection or stability but on noncoherence (Law 2002), inconsistency and, frequently, the fleeting, local, or ephemeral nature of actors' infrastructural patchwork. It surfaces too the work of boundary making and boundary crossing as a multi-infrastructural work practice.[19] And the vocabulary itself stitches together rich accounts of infrastructural work and theory from across the fields of Science and Technology Studies, Computer-Supported Cooperative Work, and Ubiquitous Computing.[20] Perhaps this exercise will graft them into a novel patchwork from which new arrangements, alignments, and actions can fruitfully emerge.

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Notes

1. As part of the infrastructure that supports National Aeronautics and Space Administrations (NASA's) space exploration initiatives and planetary science data collection, this is a knowledge/power infrastructure. I play here off Paul Edwards' (2010) description of knowledge infrastructures, and the Foucauldian theme of this dualism. Power too has a dual sense in this case: as the electrical voltage that supports site hardware and as the international agreement between two sovereign governments to treat this patch of Spanish land as if it were American soil, with all the legal and infrastructural aspects that implies.
2. Communications scholar Carolyn Haithornthwaite calls this a situation of "media multiplexity," and posits a strong relationship between degrees of media multiplexity and social network tie strength (Haithornthwaite 2005).
3. *Pace* critical geography, my use of "space" in this article refers to a shared interactional context: common ground for conversation and interaction, established through statements, formulations of place and membership (cf. Schegloff 1972). Interactional "space" is never singularly shared in the sense that all participants have the same understanding of the interaction (my thanks to Barry Brown for this clarification), and I do not mean to imply a "common ground" for singular interactions. Instead, my choice of language aims to draw attention to how actors accomplish things like work, talk, and mutual understanding, constructing a "space" for such interaction across such heterogeneous infrastructural terrain.
4. I am grateful to Robin Williams for this articulation at the Knowledge Infrastructures Workshop, Ann Arbor, MI, May 23–25, 2012.
5. Despite drawing inspiration on heterogeneity from contemporary Actor-Network Theory, my approach is more ethnomethodological in stance. The two, however, agree upon the production of visible orders through local action, and agency at the interface, whether in interactions between humans or humans and machines (cf. Suchman 2007; note 18, below).
6. Ubiquitous computing ("Ubicomp") is Weiser's term, developed at the Xerox Palo Alto Research Center (PARC): the site of foundational STS studies by Lucy Suchman and Julian Orr. Despite his young age (and early death) Weiser is considered a founder of the field and qualifies as a "visioneer" in the domain (McCray 2012).

7. Patchwork recalls Law's (2002) "pinboard" metaphor, but here I suggest something in between the distinct elements of the pinboard and the narrative whole by suggesting attention to local patchings that bring these elements together into loose alignments. More appropriate might be the metaphor of "tacking" or "basting": a practice in quilt making that loosely sews patches together in advance of permanent stitching.
8. Names and Twitter identities have been changed. The @ symbol identifies a Twitter user name. The # identifies a searchable theme across the Twitter system.
9. This interaction was also consequential for my ethnography. I added @planetgal to my Twitter feed, revealing backchatter (McCarthy et al. 2004) that was an important part of the conference experience for its attendees. Notably, Facebook played an important role in this community. Members of the team were Facebook friends, exchanging wall posts and links alongside instant messages and tweets, and my own online participation was essential to maintaining rapport and copresence with my actors.
10. For specific examples of the intersections between STS, communications, and media studies approaches, see Gillespie, Boczkowski, and Foot (2013).
11. I do not wish to imply that some systems are better at producing copresence. The seamful quality of all such interactions has implications for the work that is done and the way that work is done. Hegemonic accounts of interaction in these seamful spaces demand analysis for how they reveal the differential distribution of power across sites.
12. Early scholarship on digital work explored digital practices as distinctive to analog or "Real Life" ones (Lynch 1991; Henderson 1999; Boellsdorf 2008); recent work looks for continuities across the divide. For analytical purposes, it is important to retain an emphasis on how modes of interaction are infrastructurally mediated. At the same time, attention to how actors deploy the online or offline divide reveals the distinctions that actors draw, and how and when they matter.
13. Much as Agile developers distinguish what is in the conversation and what is not in the conversation (Cohn, Sim, and Lee 2009).
14. Spacecraft missions may be particularly susceptible to this kind of seamful misalignment. Ironically, this is not due to their high-tech status but due to significant decreases in funding post-launch that strip teams of the resources to support continued face-to-face interaction, in favor of what are considered "cheaper" alternatives through distance connectivity, yet without finances to support such systems. The teams I studied struggle regularly with off-the-shelf equipment, dropping calls and colleagues right and left. I observed one meeting in which many of the scientists were gathered together in person, but there were such difficulties with connectivity to remote participants that each scientist telephoned into the teleconference from their cell phones. They sat

in the room side by side, each plugged into the meeting through their individual headsets, watching a projection on the screen from a single computer that managed to log on to the WebEx server. In this case, the meeting could only support copresence through seamful media, instead of through face-to-face attendance.

15. This resonates with Law's (2002) recent efforts to decenter the network and the heroic vision of the heterogeneous engineer. While my analysis of actors here is not entirely symmetrical, I retain an interest in the possibilities for agency in these in-between spaces.
16. The repair work that I observed was usually undertaken by secretaries or female engineers, whose engagement with repair often signaled or coproduced lower status within the organization.
17. Inherent in this interest is a call to continue—in multi-infrastructural space—feminist Science Studies questions of how and where such networks are cut, where and how the edges are redrawn, which agencies are said to matter, and which boundaries are produced.
18. Certainly, "agency" arises here in the actor-network sense: both at and through the juncture of a variety of heterogeneous elements. It is tempting to assume that there is nothing unusual going on aside from simply expanding the size of the actor-network, and that moments of "seamfulness" only occur when actors fail to ally their resources effectively. Yet each of these systems, considered as actor-networks proper, bring their own topologies to the mix: a property that the infrastructural lens makes especially visible. Further, the new assemblages are not stable, nor are practices oriented toward their routine stabilization. Keeping our focus at the seams produces empirical opportunities by staying attuned to the combining of heterogeneous networks as an ethnomethodological problem: that is, as a question of situated actors' practices. Multi-infrastructural work therefore becomes an observable–reportable phenomenon and, in its local achievement, a marker of membership (Garfinkel 1967).
19. This is consistent with transnational approaches to anthropology that seek not only to decenter networks but also to show how identities are formed and transformed through interaction across borders, thereby producing them.
20. Such fields have been fruitfully patched before, notably in the work of Suchman (2007), Ribes and Lee (2010), Jackson et al. (2011), Dourish and Bell (2011), and others.

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