The Human Infrastructure of Cyberinfrastructure

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ABSTRACT
Despite their rapid proliferation, there has been little examination of the coordination and social practices of cyberinfrastructure projects. We use the notion of "human infrastructure" to explore how human and organizational arrangements share properties with technological infrastructures. We conducted an 18-month ethnographic study of a large-scale distributed biomedical cyberinfrastructure project and discovered that human infrastructure is shaped by a combination of both new and traditional team and organizational structures. Our data calls into question a focus on distributed teams as the means for accomplishing distributed work and we argue for using human infrastructure as an alternative perspective for understanding how distributed collaboration is accomplished in big science.

Categories and Subject Descriptors
K.4.3 [**Organizational Impacts**]: Computer-supported collaborative work; J.3 **[Life and Medical Sciences]**

General Terms: Management, Design, Human Factors, Standardization, Theory.

Keywords
Cyberinfrastructure, Infrastructure, Teams, Collaboratories.

1. INTRODUCTION
Recent years have seen the rise of new forms of large-scale distributed scientific enterprises supported primarily through advanced technological infrastructures. We refer to these as "cyberinfrastructure," although terms such as "grid computing" [11], "collaboratories" [9], and "eScience" are also commonly used. These projects have attracted significant investment from major funding agencies, substantial participation from domain scientists, and considerable interest from researchers whose practice focuses on issues in computer-supported cooperative work and science studies. We see the growth of interest in cyberinfrastructure as reflecting several trends related to "scientific collaboration" [23]. The first is the rise of "big science," which is generally traced in particular to post-WWII efforts in physics and a change in the scale of the kinds of enterprises that theoretical but especially experimental physicists might undertake [12, 26]. The second is the rise of interdisciplinarity as a significant mode of scientific practice, which is related in part to this same transition from small science to big science but is also strongly associated with changes in funding for science and the sites and contexts of knowledge production [13]. The third is a range of political and economic considerations around the locations where prestigious science is done [15]. The fourth, of course, is the spread of advanced technologies and the increasing interest in the virtual as a site for working practice.

Cyberinfrastructure draws on all these traditions, although in many ways it remains in its infancy. Cyberinfrastructure projects to date are largely developmental efforts. Cyberinfrastructure technologies are still emerging; they cannot be plucked off the shelf, but must be crafted and developed in situ. Large-scale investments in cyberinfrastructure, then, have largely taken the form of partnerships between domain scientists and information technologists, who then jointly create a new form of infrastructure for conducting science and often, with it, a new form of science.

With the exception of recent work in Olson et al., [19]; Jirotka et al., [14]; and by Ribes and Bowker [20]; few studies have focused on coordination and social practices within a cyberinfrastructure. Previous work on gathering user requirements for cyberinfrastructure [8] has shown that differences in professional cultures increased the chances for misunderstanding and mistrust (e.g. differences in design processes leading to different conceptions over the appropriate level of requirement specificity). Related research on comparatively small multi-university collaborations found that multi-university projects are even less coordinated and more problematic than multi-disciplinary collaboration [6]. Other work on interdisciplinary collaboration and smaller collaboratories provide additional insights into the human challenges of complex collaborations such as uncertainty in task and environment resulting in the use of interpersonal coordination mechanisms instead of formal organizational structures [2]. Fitzpatrick [10] suggests that a more appropriate metaphor for work practice is as a dynamic process of negotiation within and between clusters of "centres and peripheries".

In 2001, the director of the National Partnership for Advanced Computational Infrastructure and the San Diego Supercomputing Center noted that although much is heard about hardware resources or software tools, the element most critical to the success of cyberinfrastructure is human infrastructure: "*The cyberinfrastructure's human infrastructure is a synergistic collaboration of hundreds of researchers, programmers, software developers, tool builders, and others who understand the difficulties of developing applications and software for a complex, distributed, and dynamic environment. These people are able to* *work together to develop the software infrastructure, tools, and applications of the cyberinfrastructure. They provide the critical human network required to prototype, integrate, harden, and nurture ideas from concept to maturity* [3].” With a similar meaning, the establishment of a “human infrastructure” was used to help explain successful groupware deployment at the World Bank [4].

The human partnerships that are necessary for successful cyberinfrastructure efforts are recognized by scientific funding agencies in both North America [1] and Europe. In this paper, we bring this issue directly into focus. Drawing on our ethnographic engagement with a large-scale cyberinfrastructure effort, we take the notion of “human infrastructure” very seriously. We intend particularly to detail specific social practices that support the technical enterprise. We approach our data from two perspectives. First, we focus on the human infrastructure itself – the people, organizations, networks and arrangements that constitute our site as a collective entity. We then explore the infrastructure “in use” to understand how it operates in practice with specific scientific activities. Following these explorations, we will return to the broader question of just what human infrastructure is, and how it helps us in rethinking the nature of large-scale distributed work.

1.1 Properties of Infrastructure

An infrastructure is an underlying framework that enables a group, organization, or society to function in certain ways, such as the series of pipes, drains, and water sources that comprise a water system. However, our use of the term “infrastructure” is intended to suggest more than this; We want to draw attention to the usefulness of comparing the ways in which human and organizational arrangements share a range of significant properties with technological infrastructures. Drawing on the work of Star and Ruhleder [24], who brought a critical ethnographic eye to the concept of infrastructure in CSCW, we want to unpack the nature and complexity specifically of human infrastructure.

Bowker [5] proposes using an “infrastructural inversion” as a methodological device, a figure/ground reversal that places infrastructure in the foreground and reveals its relational nature. We attempt a related but distinct infrastructural inversion, not just to reveal the relationships between social groups and infrastructure, but also to think about those social groups themselves as infrastructure, in all the complexity that Bowker, Star, and colleagues reveal. By “human infrastructure,” we refer to the arrangements of organizations and actors that must be brought into alignment in order for work to be accomplished. We are interested in large-scale collaboration and want to examine the human infrastructure that enables distributed work to get done.

By outlining eight aspects of infrastructure, Star and Ruhelder attempt to make visible a series of otherwise un- or under-examined issues in how we think about our relationship to technological infrastructures. They point to the social practices and institutions within which infrastructure is embedded and by which it comes to play an important role. The eight aspects are:

- *Embeddedness:* infrastructures depend on a range of existing technical and social structures for identity and function.
- *Transparency:* infrastructure invisibly supports tasks without needing to be assembled or reinvented for each task.
- *Reach or Scope:* infrastructure reaches beyond a single event of one-site practice, and may be either spatial or temporal.
- *Learned as a part of membership:* artifacts and organizational arrangements come to be taken for granted by members.
- *Linked with conventions for practice:* infrastructure both shapes, and is shaped by, the conventions of a community of practice.
- *Embodiment of standards:* Modified by conflicting conventions, infrastructure takes on transparency by plugging into other infrastructures and tools in a standardized fashion.
- *Installed base*: Infrastructures depend on previous ones, and on existing systems of support, funding, training, and expertise.
- *Visible upon breakdown*: generally when infrastructure breaks down it is noticed; otherwise it is largely invisible.

Star and Ruhleder created this list of properties as part of an understanding that infrastructure is a fundamentally relational concept that is marked by ambiguity and multiple meanings: “*An infrastructure occurs when the tension between local and global is resolved. That is, an infrastructure occurs when local practices are afforded by a larger-scale technology which can then be used in a natural, ready-to-hand fashion* (p. 114).” They emphasize infrastructure as *temporal* as these properties emerge over time.

Star and Ruhleder consider the social and the technical aspects of infrastructure to be interwoven. Our use of the term “human infrastructure” should be considered not as a theoretical departure from that consideration; rather we use “human infrastructure” as an analytical lens with which to magnify the social. While Star and Ruhleder’s aspects focus on a moment in time where tension between local and global has been resolved, we use our focus on human infrastructure to describe the social conditions and activities that constitute the emergence of infrastructure.

2. RESEARCH SITE: FBIRN PROJECT

The data that we will present here is based on an ongoing ethnographic study of a distributed cyberinfrastructure project called the Function Biomedical Informatics Research Network (FBIRN), a large-scale project in the area of biomedical research funded by the U.S. National Institutes of Health (NIH). The FBIRN is a consortium of scientists from 13 different institutions distributed throughout the U.S.

The FBIRN is part of a larger umbrella project, the NIH-sponsored BIRN (Biomedical Informatics Research Network). The BIRN's charter is to development and support a cyberinfrastructure to encourage biomedical scientists and clinical researchers to make new discoveries by facilitating sharing, analysis, visualization, and data comparisons across laboratories. The growing BIRN consortium currently involves 30 research sites from 21 universities and hospitals that participate in one or more of three separately-funded test bed projects centered around structural or functional brain imaging of human neurological disorders and associated animal models.

The major goal of the FBIRN test bed project is to develop tools to make multi-site functional MRI (Magnetic Resonance Imaging) studies a common research practice. Single-site samples tend to be small due to the difficulty of locating and enrolling appropriate research subjects, limited access to expensive machines, and the labor intensive nature of conducting clinical assessments and in-scanner cognitive tests. Multi-site studies can ameliorate the problem of inadequate sampling in medical research, but variability among machines, software, and methods compromise the value of multi-site imaging datasets. This challenge of pooling data across sites is already daunting, but the responsibility of the FBIRN project, and its umbrella project, is larger still. FBIRN has been created to drive the development of cyberinfrastructure that is truly usable for scientists. The challenges are complex, involving technical, scientific, and organizational elements.

FBIRN is using schizophrenia as a test case. Schizophrenia is a heterogeneous disease, the study of which requires integrative methods that link psychiatric characteristics, demographic characteristics, and brain circuitry dysfunction. By taking this integrative approach, meaningful subgroups may be identified that would ultimately lead to more effective treatments.

While it will be years before FBIRN will be able to fulfill its long term goal of having a large data repository where researchers can routinely contribute and share research data to create larger or new kinds of samples, much has been accomplished in three years of work. The FBIRN has successfully developed *de novo* tools for multi-site functional MRI studies, for data collection, management, sharing, and analysis. It has collected several unique datasets that include imaging and assessment data from ten different universities; the tools, methods, and datasets in their initial forms are currently available to the research community.

The Principal Investigator (PI) of FBIRN is responsible for overall project coordination and is supported by project administrators and a steering committee that is composed of working group chairs. The leaders of FBIRN, in consultation with the External Advisory Board and the BIRN Executive Committee (BEC), provide coordination and assistance with unforeseen obstacles. The BEC is the governing body of the BIRN and includes the PIs from each of three test beds, the BIRN Coordinating Center (BIRN-CC) and the NCRR Program Officers.

At the time of writing, we have been engaged with this group for 18 months. We have undertaken participant observation at 36 bi-weekly meetings, remote teleconferencing and videoconferencing meetings of various working groups and all-FBIRN meetings, and half-yearly all-hands meetings and have also read associated email list messages. Because the work of FBIRN is distributed over time and space, and because most workers only work on FBIRN part-time, a critical means of data collection has been through one-on-one interviews. Twenty in-depth interviews have been completed with individuals from ten different institutions. Interviewees worked on the project for the following lengths of time: 6 months to a year (2 subjects), 1 to 2 years (4), or 2+ years (14). Interviewees self-described positions within the FBIRN were: research site PIs or co-PIs (4), engineer/developer (5), neuroscience researcher/research associate with doctorate (4), working group chair (2), project manager (1), neuroscience graduate student (1), psychology postdoctoral fellow (1), research assistant (1). This research serves to unpack the work of a cyberinfrastructure project from the perspective of a diverse membership. Pseudonyms have been used.

3. SOCIAL GROUPS IN THE FBIRN

In large-scale distributed collaboration, one might first think of distributed teams as the primary means for conducting work. Indeed, the official description of the FBIRN organization suggests a familiar unit of analysis: working groups. FBIRN working groups are known to perform the work of creating cyberinfrastructure. Though they seem clearly identifiable as teams, we found that working groups differ from how teams are usually considered in CSCW in substantial ways. We argue that teams should not be viewed as the fundamental unit of analysis for a human infrastructure.

Our research also finds that organizations like FBIRN consist of personal networks which exist alongside traditional collaborative structures and other, more diffuse, mechanisms for coordination. We find that people are members of multiple networks, groups, and "traditional" organizational structures, and work within whatever structure is necessary to accomplish their work.

3.1 Not-so-Virtual Laboratories

Current interest among cyberinfrastructure researchers focuses on virtual organizations (e.g. Foster and Kesselman, 2004). However, the importance of real place-based organizations to cyberinfrastructure cannot be overplayed. FBIRN describes itself as a consortium of universities or laboratories and these units are instrumental in working to create the FBIRN.

The researchers involved in the FBIRN depend heavily on their "traditional" organizations, called *research sites*, such as universities, hospitals, departments and laboratories for many kinds of support, e.g.: recruiting test subjects, scheduling tests, conducting psychological assessments, collecting genetic samples, purchasing and maintaining expensive MRI machines, testing subjects for the MRI machines, testing subjects in experiments, conducting statistical analyses, not to mention providing the pens, pencils, fax machines, computers for data storage and analysis, and maintaining computer networks. Traditional organizations thus play an important role in supporting human infrastructure.

Although teams should not be viewed as the fundamental unit of analysis for human infrastructure, traditional teams do play an important role. Labs with several people in the FBIRN project tend to have regular FBIRN group meetings. Regular meetings are most common at laboratories where there are many project participants, both official and unofficial, co-located in the same building. Senior members at each site typically report depending on their juniors at the lab to keep them apprised of various FBIRN working group activities.

The relationship between global cyberinfrastructure efforts and local sites is more than simply one of support. The conditions of local sites also set the context for participation in the broader enterprise. Partnering with other institutions may be a way to achieve access to expertise, collaborators, data, subjects, support, equipment, or prestige. Participation in the larger effort, and one's individual and institutional role within the larger human infrastructure, arises in part in response to local needs, and must be continually managed with reference to them.

3.2 Working Groups and Task Forces

After research sites, the most visible groups of collaborators in the FBIRN are the *working groups* and *task forces*. Internal working groups were formed by FBIRN to focus on specific areas of development or application. The current working groups are: clinical, calibration, cognitive, statistics, and neuroinformatics. Working groups are the primary site of collective action in FBIRN: they bring people together across both disciplinary and geographical boundaries. Working groups coordinate their own activity; bi-weekly status meetings supported by video conferencing and telephone provide opportunities for global coordination. FBIRN scientists participate in one or more working groups and almost all of the working groups involved individuals from almost all of the sites.

In contrast, task forces were formed by and for the external BEC to discuss cross-test bed concerns. Task forces included data sharing, IP (intellectual property), and IT. All the task forces included some people from each test bed project.

3.2.1 "How they're named doesn't matter"

For participants there was a surprising amount of confusion over the composition and names of the working groups and task forces. For instance, the 'Cognitive working group' is also called the 'Cognitive Challenge working group'. When questioned about whether there was a difference between these, one of the participants took several seconds to conclude that they are the same. Outsiders were confused as to whether they were the same group, but suspected that they were. Participants and non-participants alike would use 'IT working group' and 'Database working group' synonymously. The group was later renamed the 'Neuroinformatics working group' to better reflect what they really did. When asked if the Database and IT working groups are different or the same, one of the neuroinformatics group's most active members replied, "*They are almost overlapping. They're not exactly the same and they change names so often. I don't know whether they still exist as two separate entities or if they are a single entity because the groups form and dissolve quickly*." He then briefly described the activities of the IT task force and the database working group, conflating the two together. Finally he concluded, "*I'm not actually forming those groups. How they're named doesn't matter actually so much. So I don't pay that much attention. I participate in the telecom for the Database group*."

Many of the participants interviewed did not know the difference between a working group and a task force. Working groups are test bed specific (e.g. just FBIRN), whereas task forces are charged with planning and developing for the entire BIRN. Whereas those involved in the task forces knew the difference, FBIRN participants who were not involved did not. A typical response when asked the difference between a working group and a task force was: "*I don't know. If you find out let me know!*"

3.2.2 Fuzziness in group membership

Others have found that team membership and team borders are often fuzzy in distributed organizations [17]. We found something even more surprising: *FBIRN participants often did not know whether or not they themselves were part of a team.* In particular, FBIRN members frequently had no idea if their task forces were still active or if they were even part of a working group.

There are several reasons for this phenomenon. Some individuals may have only a passing interest in a working group area and only participate as they are solicited. Due to their infrequent participation, they consider themselves to be peripheral. Their peripheral status renders them uncertain as to their own membership status. Participants know with which working groups and task forces they have worked previously and with which groups they participate regularly (although they might not know what those groups are named), yet there is no clear line between "in" and "out", rather there are varying degrees of participation that renders membership unclear. This ambiguity is not limited to the periphery, however. When asked whether they belong to a working group, some active participants answer that they aren't sure but that they participate in the teleconferences. Teleconference participation *suggests* membership, but has not been fully embraced as *defining* membership.

Task forces and, occasionally, unofficial working groups become active as the need arises and become inactive when need subsides. One investigator remarked that she didn't know if she was on a particular task force or whether it was still active. She figured that the executive committee would let her know.

What is most important to us here is not simply that people were uncertain as to their own participation in working groups or task forces or in the FBIRN as a whole. Rather, we were interested to find out how the people of FBIRN are able to successfully collaborate without knowing their team membership and team borders well.

3.2.3 Fuzziness in organizational membership

While the "inner-circle" of the FBIRN, i.e. the senior investigators at each site, and those who participate in many cross-site meetings, is identifiable to most participants, there is no defined outer periphery of membership. For example, on the extreme periphery, hospital research coordinators may collect crucial data for the BIRN yet know little or nothing about FBIRN or the BIRN Project. Although FBIRN participants know that there are people who perform these tasks, they may not know who these people are at their own site and very few know who they are at other sites. Closer to the center than hospital coordinators, are graduate students or postdoctoral researchers who are familiar with the FBIRN project and its goals and who help to collect psychological assessment data by interviewing patients or setting up cognitive experiments with the MRI. These participants usually only interact with their direct supervisors, who are typically senior investigators, and may only talk to other FBIRN members in a training session or if a problem arises. They are marginally visible.

Clearly, the extent to which the entire project is visible varies with respect to organizational position; those closer to the management of the project have a broader view of participation, although this broader view is, at the same time, fuzzier since it encompasses institutions and several key members, but not necessarily those who are not engaged directly with a scientific problem or technological innovation. Participants may have a clear view of who is working in their department and yet lack a complete view of what the difference is between a task force and a working group; what those task forces and working groups are named; and who is working on the project at any given time, yet this multisite project moves forward successfully.

Rather than being a disadvantage, not having a clear view of the FBIRN membership may actually be advantageous for collaboration. In a large-scale cyberinfrastructure project, people develop selective views of the entire network. The complexity of all the different working groups, lab memberships, and disciplines is far too great for any single member to follow. Thus, members develop selective knowledge for those aspects of the human infrastructure that they need to interact with in order to coordinate. This imperfect knowledge of the network may actually be *ecologically beneficial* for interacting in the network. The complete organizational structure is, in many cases, hidden from view for those who participate in it.

Thus, organizational membership is fuzzy. Although the list has since been updated by each site, for approximately one year, there was no up-to-date FBIRN participant list. The directory on the BIRN website included according to one FBIRN worker, "*secretaries that have been gone for years*". The hard-working project manager is a key member of the FBIRN team and a major point of coordination. She, and also perhaps her assistant, know better than anyone else who is involved in the project. However, even she does not have a complete list of all FBIRN participants;

indeed, on being naively asked for one by us, she expressed confusion that we should expect such a thing to even exist. She maintains a list of email addresses that receive announcements, but it is not an accurate representation of the entire project team because it includes people who simply wish to be kept aware of the project's progress or people who are no longer on the project. While the project manager knows the principal site investigators at each site, the turnover of other participants is so rapid that she no longer tries to keep track. In academic research, postdocs, staff, and researchers come and go; it is an impossible task to maintain a participant list. Consequently, each research site has been charged with maintaining their section of the contact database. Turnover of FBIRN staff, it must be noted, occurs even more quickly than the turnover of academic staff positions because workers often have their time redistributed by their supervisors. Their efforts can be suddenly directed to a different project entirely. A person working 50% time on FBIRN one month could very well be working 10% time the next. Thus not only is there limited visibility, but membership is frequently changing.

What is remarkable is not that those participating in the project have a limited organizational view, rather what is remarkable is that the organization continues to function in the absence of this sort of mutual visibility. *Participants can successfully accomplish work with a partial view of the organizational membership and structure*. This extends Star and Ruhleder's notion of infrastructural transparency. Transparency refers to how infrastructure does not need to be assembled for each task; FBIRN members know what part of the infrastructure they need to tap into to coordinate, get information, or to perform a task.

3.3 Personal Networks

Networks have been viewed from different perspectives in CSCW. A form of human network used for coordination of work is what Engeström et al. [7] terms "knots", which are loosely connected networks of people where roles are fixed. The type of human network that we found in FBIRN is similar to what Nardi et al. [18] describes as *intensional networks*. Increasingly, traditional organizational structures are being replaced by networks of people formed to work on particular projects. However, personal networks often remain after the project is finished, as people are bound together based on their common work experience. These networks aid organizational members in local coordination. Nardi et al. found that these networks are formed deliberately and consist of two properties: *emergence*, formed to accomplish particular tasks, and *history*, which enables their rapid formation. These networks, they note, can exist alongside traditional teams.

When asked how they joined the FBIRN project, some mentioned answering a solicitation from the funding agency or a job ad, however the majority of interviewees became involved in the project through their boss (being reassigned) or through seeking work through contact with someone in their personal network. Each person we interviewed had their own unique set of collaborators. Networks were formed based on having similar domain knowledge and interests, location at the same, nearby or previous work sites, conferences attendance, and collaboration on other non-FBIRN projects. For example, participants found their positions by meeting people at conferences, through being a former student to a project member, through a recommendation by a collaborator, or through a colleague or boss. Personal networks were used to bring workers to the project, but personal networks are also important for accomplishing work.

FBIRN participants mentioned having a set of people at their own site and other sites who were useful sources of help and information. Unsurprisingly, the more senior the researcher, the larger the number of collaborators were named. Of all the working groups, the neuroinformatics group seemed to be by far the most cohesive as most of them named each other as collaborators. Yet these researchers also had their own personal networks on which to rely for getting specialized information such as clarifications and explanations of clinical terms or research practices.

The FBIRN not only benefits from personal networks, but it *cultivates new networks and reinforces others*. One senior investigator noted that because of mutual participation in FBIRN, at schizophrenia conferences all of her FBIRN colleagues would get together at least once. A few of these colleagues were former co-workers from previous places of employment while several others had been previously unacquainted. As some participants noted, meeting face to face is an important way to build trust and collegiality and also to solve problems and plan ahead.

Using personal contacts, individuals recruited people to meet the needs of the current work project. Networks are not stable. These relationships require effort to create and maintain and may be selectively activated. Personal networks thus *augment* collaboration as part of the human infrastructure in addition to more traditional organizational structures (e.g. working groups) by organizing access to information and human/technical resources.

3.4 Synergy with Other Collaboratories

Membership in big science projects can become blurred on an even larger scale. Although we speak of the FBIRN as a distinct entity, it is hard to separate FBIRN from its sister testbed collaboratory project in the BIRN, as a huge number of personnel are shared. Although our research focuses on FBIRN, it is closely allied with one of the other two testbed projects and the grid computing center.

One respondent did not think of FBIRN as separate but rather as part of one large BIRN project, or as she put it "*one big smudge*". Indeed the task forces are BIRN-wide, and some tools being developed had similar antecedents or cross-testbed applications, so for some individuals the work they do is relevant to more than just FBIRN. For others the work they do for a testbed is distinct.

FBIRN personnel work in related consortiums and make frequent efforts to learn from other cyberinfrastructure projects. In grant proposals, FBIRN advertises the participation of researchers and developers in other research groups as evidence that participants have experience with similar projects, and knowledge that can be useful to FBIRN. This cross-pollination of research groups is actively encouraged and at the annual all-hands meeting for all BIRN projects, individuals from other projects were invited to share their expertise and to engage in collaborative projects. Indeed many of the FBIRN participants felt that their participation in other related research groups informed and enlightened their work in the FBIRN. One "sister group", NAMIC is composed of computer scientists who design algorithms and tools. Many FBIRN scientists are involved and provide legacy data. Meanwhile, NAMIC is developing translational tools that will be of use to FBIRN.

The MIND (Mental Illness and Neuroscience Discovery) consortium is similar to FBIRN in that it does both functional and structural imaging and collects assessments. Whereas the FBIRN cyberinfrastructure-in-progress uses distributed computing by definition, MIND has a centralized model where all data is entered into a single database and made available to other sites. The functional tasks, including cognitive tasks, are almost identical for each consortium; while some data is not comparable, MIND and FBIRN seek ways to combine data sets.

The overlap between MIND and FBIRN is significant. By the estimation of one FBIRN investigator, approximately 80% of MIND is participating in FBIRN and conversely 20% of FBIRN is part of MIND. Most of the FBIRN participants were extremely positive about the collaboration between MIND and FBIRN and were deeply committed to free exchange between the consortiums. There were difficulties early on, where. e.g. one participant noted that people involved in MIND "*were saying that folks couldn't use certain data sets, and certain people shouldn't be talked to, and the attribution of certain things are to be MIND and not to FBIRN*." One FBIRN researcher even demurred to discuss a certain topic with an FBIRN colleague because he was working on that same topic for MIND. Certainly with so many individuals working across projects, conflicts of interest will inevitably arise. However, most of the common FBIRN and MIND participants found everyone was very supportive and that the consortiums were mutually beneficial.

When we asked one FBIRN and MIND participant if there was personnel overlap between the two consortiums he said: "*I think the problem with word overlap is that it's like redundancy and we don't want redundancy. We want leverage. We want synergy. They have a lot of personnel in common but if you look at the mandates the BIRN has—and I've asked GE how many people it would take to do a project like this and they would say, 'I'd probably need 300 to 400 people'. And that's the scale of the problem. In the academic world people have to get grants and get funded by NIH and they have a lot to promise and they hope to get it done. The only way realistically to get it done is to leverage and cooperate between groups that have similar enough goals, and importantly they have distinct commission as far as the NIH is concerned because you can't fund the identical thing twice. But if they're close enough they could work really well together. That's the way it should work*."

We found then that in the BIRN projects, human infrastructures do not exist independently of other collaborations. Building on Star and Ruhleder's notion of embeddedness, we find that certain aspects of FBIRN's human infrastructure, such as learning and experience, can be used from and by other cyberinfrastructure projects. Thus, the success of cyberinfrastructure projects benefits from the ability of a human infrastructure to be able to leverage existing technical and social arrangements from similar projects.

3.5 The Hybrid Nature of Big Science

Our findings suggest an organizational form for big science that is a hybrid of the old and the new. Traditional organizational forms are the foundation of work, but they are embedded in new contexts. Human infrastructure in large cyberinfrastructure projects is a vast series of overlapping traditional organizations, consortiums, loosely organized groups, and networks.

The networks which are part of the human infrastructure of FBIRN reflect professional identities, disciplinary alignments, and historical trajectories. The FBIRN site investigators are often people who share an intellectual allegiance to particular methods, research interests, laboratories, departments, or institutions. They came to the FBIRN through different paths and found themselves as coworkers in FBIRN's distributed organization. The FBIRN is one of a series of projects over the career history of investigators who may have worked for years in the same domain, attended some common conferences, and may have collaborated in the past; Alternatively, they may have only heard of each other and have never collaborated before. The FBIRN strengthens existing relationships, but it also creates many new research collaborations. It would be fair to say that FBIRN is enmeshed in a series of social networks that extend beyond the rest of the BIRN and related research consortiums. Several participants noted that the people with whom they spoke most, outside of their physical location, were those with whom they collaborated on other consortiums or other BIRN testbeds. Cyberinfrastructure efforts themselves create these contexts. Ribes and Bowkers' [20] describe how those responsible for the technical aspects of the GEON collaboratory ontology development are veterans of previous similar efforts, a roving band of ontologists who draw upon previous experiences and networks.

Working groups are not teams in the traditional sense; rather they act as a conceptual space for types of problems. Suchman [25] and Schmidt [22] talk about a roadmap as a way to guide people through the course of their work. A human infrastructure is more like a blueprint that enables people to figure out the basic who, what, and where of conducting big science. A blueprint gives one an idea of how parts of a building fit together and what functions they have. A blueprint can delineate a heating from a plumbing system, in the same way that teams or networks can delineate work. Furthermore, the amount of personnel overlap amongst testbeds and collaboratories suggests that collaboratories themselves may be conceptual spaces to delimit areas of work. Thus, given that participants have a limited view of their team and organizational membership and structure, teams, organizations and networks that are part of the human infrastructure can work as representational rough "maps" of a conceptual space that help people to delimit and define areas of work.

4. HUMAN INFRASTRUCTURE IN USE

We now turn our attention to examples of the subprojects of the FBIRN. In comparing them to Star and Ruhleder's properties of infrastructure, we hope to tease apart the ways in which human infrastructure simultaneously benefits from existing infrastructures and also contributes to building the cyberinfrastructure-in-progress. In this way we can document how human infrastructure helps cyberinfrastructure to emerge.

4.1 New Practices, Old Conventions

In designing their data gathering exercises, one of the many decisions FBIRN scientists made was which clinical assessment protocols (psychological surveys) to adopt as the database had to be constructed to accommodate the data produced. Choosing an instrument to rate symptoms proved to be challenging because the clinical researchers involved each had their preferred instruments. SANS, SAPS, and PANNS are standardized clinical assessments that have been developed to aid in the diagnosis, evaluation and rating of symptoms. Each clinical researcher is concerned with different types of schizophrenia which can be associated with different combinations of symptoms. Each assessment added quite a few additional questions to the database. Rather than forcing any of the clinical researchers to change their preferred instrument, the group was able to find a solution that satisfied everyone: By using a subset of questions taken from the SANS and the SAPS and adding four questions from the PANSS, a PANNS equivalent could be constructed.

We see so far that the human infrastructure of FBIRN already has some infrastructure properties that Star and Ruhleder describe: Existing standard instruments, such as the SANS, SAPS, and PANSS, have already been learned as part of membership, they have reach beyond a single site, are linked with conventions of practice, have paper forms that embody standards, and are built on an installed base of approaches. Thus, the human infrastructure is able to create new practices that link to current conventions of practice.

4.2 Experimentation and Negotiation

Choosing cognitive tasks to run on test subjects in the MRI machines is a labor-intensive effort. Much data was collected by FBIRN for the purpose of seeing if the tasks provided the desired types of activation and if decisions were made primarily on the basis of the data collected. A good task activates areas of the brain that are affected by schizophrenia robustly in different scanning environments.

Each researcher has their favorite experiments and even for fairly standard types of experiments such as "auditory oddball" tasks (where test subjects must listen for an aberration in a series of sounds), there were long discussions about the best auditory stimuli. In order to settle questions over which method to use, the researchers of the BIRN conducted numerous experiments at several sites to determine which methods produced the strongest activation in the brain—usable data with high statistical power. Methods had to be robust enough to generate activation across sites using different machines and under occasionally suboptimal conditions, such as having patients who could not stay still.

Researchers with similar expertise and backgrounds worked closely together to choose cognitive tasks for FBIRN. For example those who were experts with an EEG-based tool, Event Related Brain Potential (ERP) conducted ERP studies and chose tasks that elicited good brain activation. Over time, FBIRN developed a new process for developing experiments.

We see that rather than being taken for granted, artifacts such as cognitive tasks are studied and negotiated. Through the interaction of participants using multiple methods such as ERP and MRI to investigate shared tasks, human infrastructure renders artifacts highly visible so that they may be discussed, agreed upon, and used, thus moving to the creation of new conventions. The human infrastructure of the FBIRN facilitates the process of choosing cognitive tasks using the following infrastructural properties: it uses methods and approaches that reach beyond one site, it utilizes existing conventions of practice, and it builds on an installed base of methods (i.e. existing expertise). We observed in the case of FBIRN that human infrastructure enables experimenting with new practices and embedding of structures, social arrangements, and technologies–i.e, infrastructure emerges over time.

4.3 Sharing Data

Sharing data is the ultimate goal of FBIRN. However, in order to understand data sharing, it is important to understand that FBIRN requires the handling of many different kinds of data in many contexts and that "data" means different things to different people. A general discussion of "data sharing" becomes almost, but not quite, devoid of significance. Thus, we need to be more specific about what it means to work towards enabling data sharing. For FBIRN participants, sharing involves policies, standards, or tools. The work of figuring out how to share data fell across domains, research sites, and levels of seniority. Project managers and working group chairs work towards ensuring that communication occurs between people doing different types of work.

4.3.1 Policies

Establishing data sharing policies is extremely complicated. Decisions must be made about who should have access to data or machines and how much. These questions require the alignment of many institutions. To answer questions of data access requires that each research site submit an individual application to their university IRB and/or laboratory attorneys. The FBIRN grant stipulates that the data must be shared with the general research public, but universities approve release of the data beyond BIRN researchers only under restrictive Federal guidelines. Problematically, each university has a unique way of interpreting Federal guidelines and adopting the most draconian measures of each as a lowest common denominator would strip out so much data that it would severely limit its usefulness. Currently each site is collecting as much FBIRN data as allowed by local guidelines. Data sharing policy must cover not only data access, but also minimum standards for involvement and participation. Policies have a direct effect on how BIRN-CC designs the computational infrastructure including specifying requirements and subsequently building tools that provide and restrict access to data, computer time, software, and hardware.

4.3.2 Standards

The BIRN-wide Ontology Task Force is charged with creating the policy for BIRN ontologies, standardizing terminologies across FBIRN and the sister test beds. Creating a new ontology for any domain is a huge undertaking that requires specialized expertise and time, both very expensive. The mission of the Task Force, with representation from FBIRN and the other testbeds and BIRN-CC, has evolved as the understanding of the task at hand, and the needs of the network, have evolved.

Originally the task was considered a "simple" mapping between fields of the databases within the network; The task force wanted to use and build on existing ontologies or standardized terminologies such as UMLS or Neuronames. The decision to use and build on existing ontologies was understood to be a compromise. According to one respondent: "*One of the problems with this has been the slapping together of things that are odd bedfellows. They're in a different language, a different syntax. The language may superficially look right, but the rules of the grammar and the syntax of these are different. You can't just simply put them together… The NIH they give you a deadline and you don't really have time to or the resources to remake this entire tool. People are doing the best with what they can do, but because of the time pressure and lack of resources it's not completely being done correctly I think.*" As the task force continued to work on interdisciplinary standardization of terms, the limitations of pre-existing resources was identified and new expertise was involved.

Independently of FBIRN, other consortia such as the National Center for Biomedical Ontologies, were formed. The task force's interaction with those consortia has created new understandings within BIRN of what ontologies are, the scope of the problem in knowledge management and automated reasoning methods, and the changing state of the ontology development field. Thus a set of "best practices" for network ontologies and lexicons was developed and agreed to, and work is continuing.

Out of necessity, each test bed is now developing their own ontology by domain scientists and ontology experts. FBIRN is building an ontology of cognitive experiments. Initially it was difficult getting the right people to participate, both because the importance of ontology development was not entirely appreciated by many in the network, and because the scope of the problem was ill-defined and constantly shifting. In order to create an ontology, domain knowledge is needed, but because ontology creation is not a typical research agenda with immediate benefits, it took time to encourage non-ontologists, such as clinical researchers, to get involved. Human infrastructure both requires and facilitates articulation of data sharing problems.

4.3.3 Tools

While ontology development is led by BIRN-CC, developing tools specific to multi-site imaging data sharing falls to the FBIRN neuroinformatics group. One of the larger tasks of the neuroinformatics working group is to create an XML schema to transfer experimental data e.g. statistics, series of huge image files, clinical assessments, and scanner visits. The schema was not developed in a void, however, as BIRN participants have been interacting with the National Institute of Mental Health (NIMH) which has been developing a data format called NIfTI (Neuroimaging Informatics Technology Initiative) for functional imaging experiments. NIfTI-1.0 was released and now work is underway to develop NIfTI-2 which will accommodate more of the information required by researchers and may even incorporate part of the schema developed by FBIRN. Keeping everyone in FBIRN aware of the collaboration between FBIRN and other collaboratories can be challenging. During one incident an FBIRN participant admonished FBIRN members to "*get on board*" with the NIfTI standard, not realizing that the neuroinformatics working group was already engaged with NIfTI.

Human infrastructure is integral to the painstaking process of creating a data sharing infrastructure that is both dependent and constrained by conventions of practice, existing standards and the organizations that created them. Each level of work within FBIRN, whether creating data sharing policy, standards or tools has ramifications for the other levels and must engage with other similarly multilayered infrastructures. The human infrastructure facilitates the connections and communication among people and practices to lay the groundwork for developing data sharing.

4.4 Human Infrastructure in Flux

Rather than being amorphous, human infrastructure might best be described as multimorphous, holding more than one shape at once and also changing shape over time. It is this multimorphous nature that is the underlying framework for big science collaboration. This flexibility is what lends human infrastructure its strength and allows it to meet demands quickly. Yet human infrastructure is messy and chaotic and difficult to manage. The diffuse and changing structure of human infrastructure changes traditional power structures and stresses maintenance relationships.

4.4.1 Recursive formation

The formation of the BIRN is recursive. Though people hold relational views of infrastructure, a physical infrastructure is slow to change [21]. Electrical wiring or routers are generally firmly in place though perspectives on these can change, depending on one's relationship with the infrastructure, e.g. if one is a user or tech support person. In contrast, human infrastructure is far more dynamic. As members discover their needs, the infrastructure is modified in a recursive type of relationship. The infrastructure is used by people to negotiate work, and in response to these interactions, the shape of the infrastructure itself is continually negotiated and changed.

Originally, FBIRN had no statistics working group, only a calibration group that was primarily concerned with the physics of the MRI, including setting up the machines to get consistent images. The statisticians felt that they often had little to contribute to these discussions and were more interested in focusing on developing statistical approaches towards measuring site differences. As a result, a statistical working group was formed. However, for quite some time different statisticians worked independently on parallel tracks. Eventually, the working group chairs worked with people to identify areas of interest within the statistics domain and over time developed four sub-working groups: reliability and calibration, data processing, algorithm development, and statistical and FBIRN programming integration. Working groups are formed as needs arise and new working groups can be formed out of existing ones. Infrastructure can thus emerge recursively.

4.4.2 Power structures subsumed

The evolving networked organizational structure subsumes channels of power that would be available in a traditional organizational structure. Several FBIRN participants in managerial roles bemoaned their lack of ability to hold collaborators accountable. Others noted they were unable to pressure those who were their equal in seniority. Those in supervisory roles, have difficulty also. One working group chair wondered how to get people to fulfill their promises when he didn't sign their paychecks and consequently developed techniques, such as asking people to set their own deadlines, to make people in his group feel accountable. While the PI of the entire FBIRN project has the power to cut off funding from research units, this is considered a final and destructive measure.

5. RETHINKING DISTRIBUTED TEAMS

In the course of explaining the case of cyberinfrastructure in the FBIRN, we have made considerable use of the concept of human infrastructure. We introduced the concept vis-a-vis the work of Star and Ruhleder, and then used it in approaching and organizing our empirical material. However, we now return to this idea and explore in more detail exactly the implications for theory.

Star and Ruhelder perform an "infrastructural inversion," bringing the infrastructure into the foreground, and therefore turning our attention towards the ways in which infrastructure emerges and the processes that render systems as infrastructural at particular moments and for particular people and purposes. This inversion points out the social processes through which infrastructure comes about. We perform a related inversion – one that applies the notion of infrastructure to the social settings within which technology is embedded. Our goal is not to differentiate human infrastructure from those infrastructures that concern Star and Ruhleder. Rather, we want to explore the ways in which their observations concerning what we might term "artifactual" infrastructures – systems, technologies, techniques, organizing schemes, and so forth – apply also to the human and social structures that sustain them. Nor has our goal been to detail the properties of human infrastructure, except as they illustrate the relationship between human infrastructure and broader infrastructural concerns. Rather, we employ human infrastructure as a lens to understand the work of FBIRN. It gives us a new way to understand organizational work, in contrast to traditional organizational structures, distributed teams, or networks.

In many ways, the concept of "infrastructure" as a noun is distracting. Drawing on Star and Ruhleder, we have adopted a relational and processual view of infrastructure; we are more concerned with "infrastructur-*al*" and with "infrastructur-*ing*" than with infrastructure per se. So, when we describe human infrastructure as "the arrangements of organizations and actors that must be brought into alignment for work to be done," we rely on these processual and relational accounts of infrastructure to emphasize the issues of arrangement and alignment.

We are accustomed to hearing arguments advanced about the changing nature of work and collaboration. CSCW is quite used to looking at forms of distributed work and virtual organizations that span geographical and institutional boundaries through the use of IT. The idea that technology might be able to create a virtual space for interaction, a site at which people can come together and engage in collective (albeit contested) activities, develop and share new practices, and (in the case of scientific work) generate new scientific knowledge, is by no means unfamiliar, because it fits into a conventional picture of traditional, hierarchical organizations being replaced with dynamic, networked organizational forms. What we find though, is that these ideas fit at best poorly as ways to understand FBIRN.

Traditional organizational structures tell part of the FBIRN story, but fail to account for the whole. Clearly, those structures enable coordination across time and across distance. A loose hierarchy stitches together disparate efforts and provides for communication and management. At the same time, a number of problems arise when we adopt this view, such as the issues of sanction and management, the question of different organizational embeddings and institutional accountabilities, the difficulty of coordinating over standards and procedures, the different working styles that obtain in different disciplines, different organizations and groups, the dynamics of the work, and the role of longer-term, informal patterns of contact and collaboration.

Distributed teams tell part of the FBIRN story, but also fail to account for the whole. Clearly, people come together in dynamic, interdisciplinary arrangements that cross organizational boundaries and respond to immediate and changing needs. However, much of the work does not have this flavor; not only are team boundaries unclear, but even one's own membership in those teams is uncertain; the concept of "team" seems to apply poorly when people do not even realize that they are members. The notion of distributed teams does not account well for the variety of local factors that condition entry and forms of participation.

Personal networks tell part of the FBIRN story, but similarly fail to account for the whole. FBIRN includes many overlapping networks and is embedded in others. The FBIRN facilitates new professional networks and extends others that members have been building for years; it provides them with new points of contact, and they use these contacts to manage their own participation in the project, to get new things done, to find new opportunities, and to extend the scope of their activities.

What we find at work is a much more complex and heterogeneous form of organization than any of these accounts provide. By thinking about participation in terms of human infrastructure, we gain a rather different perspective. Infrastructure mediates between the local and global. The Internet allows us to transform a global concern (how can we make information available to people all over the planet?) into a local consideration (what sort of cable will connect my computer to that hole in the wall?); information infrastructures (such as ontologies) provide a means to understand the global properties of information collections through a series of local alignment practices. The human infrastructure of cyberinfrastructure achieves collective action not by making my relationship to the whole visible but by making it invisible, indeed irrelevant. The human infrastructure does not create a distributed team; it dissolves the very need for one.

If the notion of team dissolves here, then what of the virtual space that brings that team together? We find it useful here to turn to Miller and Slater's analysis of Internet use [16]. Drawing on ethnographic material gathered in Trinidad – a site outside the traditional settings of Internet development and deployment, but also a site embedded in significant transnational flows of people, information, and capital – Miller and Slater suggest that our notion of the Internet as creating a virtual space apart from the realm of everyday life is mistaken. What they find instead is an Internet which is always already local. The Internet is not a disconnected, disembedded domain to be naturalized for Trinidad; rather, the Internet emerges as something "continuous with and embedded in other social spaces." Similarly, in the case of the FBIRN, people are not grappling with a disembodied and disembedded global cyberinfrastructure, but rather a series of local concerns and arrangements which blend in and can be achieved through a human and technological infrastructure. The cyberinfrastructure provides a means of producing and transforming local concerns – institutional prestige, academic power relations, organizational relationships, access to appropriate scientific data, access to subjects, and so on.

The metaphor of networks is an apt one. Collaboration in FBIRN is supported by both technological and human networks. However, these networks vary in their forms and in their use. Frequently, they are not resources to be activated or tools for achieving ends; they are the unseen conduits through which work flows. They recede into the background; they become transparent in use. We have found the metaphor of infrastructure useful here precisely because of the way it allows us to talk about the human structures relationally in just the same way as we might approach technological infrastructures in CSCW terms. Star and Ruhleder's explorations of infrastructure required that we abandon an easy view of systems that "just work," and that we take a more nuanced view of the role of technology in supporting collaboration, and pay attention to the processes by which technological elements might be rendered infrastructural. We have argued that a view on human infrastructure might equally serve to problematize the teams and networks by which distributed collaboration is frequently, and perhaps all too easily, explained.

5.1 Implications for Infrastructure Building

In cyberinfrastructure projects, the difficulties facing smaller collaborations and collaboratories seem to be compounded. Given vast expenditures by governments internationally to radically transform and contribute to science through cyberinfrastructure and e-Science projects, the need for research will continue to grow. While the primary contribution of our paper is theoretical, our study suggests some practical implications for those wishing to support the human infrastructure of cyberinfrastructure.

Our data reveal that organizational and instrumental support are critical for the rapid formation and dissolution of both temporary and long term task-driven working groups. The fluid, "fuzzy" memberships are indicative of a highly flexible, quick-response way of working. Given an almost inevitable shortage of workers and the demands of innovation, while ambiguity should be reduced when possible, fluid organizational structures should be embraced and encouraged as a strength.

Related to above, working groups and project roles have varied needs and require ongoing organizational and instrumental support for dataconferencing and teleconferencing that target these needs. For example, groups varied in their mobility and data-conferencing needs for images. One size won't fit all.

Especially because of project scale, and "fuzziness" of perceived group membership, face to face work group meetings are indispensable to increase shared understanding, productivity, and accountability. For some groups, meeting at disciplinary conferences may be appropriate, for others a special meeting may be ideal. The fuzziness of perceived group membership requires special efforts to encourage broad participation.

Big science should not lead to diffusion of responsibility for coordinative resources. As part of the project mandate, individuals need to be responsible for tracking, organizing and disseminating working group and administrative information resources (e.g. information dispersed across multiple websites, wikis, mailing lists, online databases, etc.) to be easily accessible to both inter- and intraproject collaborators and new hires.

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