Making Infrastructure: The Dream of a Common Language

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ABSTRACT
Can the principles of participatory design be applied in large infrastructure projects? We address our experience as social scientists co-developing a larger digital library project funded by the US government. We focus on how to understand the ways in which potential use, new and old infrastructure, and large project organization interact. We use three concepts: commitments, object worlds, and trajectories, and their associated processes (crystallization, maintaining ambiguity, finding users, and building on the inertia of the installed base). We discuss the importance of linked visions and dreams, drawing on Watson- Verran's notion of "imaginary."

Keywords
Information infrastructure, digital library, object world

INTRODUCTION

> Resources appear, too, as shared visions of the possible and acceptable dreams of the innovative, as techniques, knowledge, know-how, and the institutions for learning these things. Infrastructure in these terms is a dense interwoven fabric that is, at the same time, dynamic, thoroughly ecological, even fragile. (Bucciarelli, 1994, p. 131)

> Tell that its sculptor well those passions read
> Which yet survive, stamped on these lifeless things
> -Percy Bysshe Shelley, 1817

How does one understand the connection between emerging infrastructure, knowledge, and practice? Can the principles of participatory design be applied in large infrastructure projects? What scales and what does not? In this paper we address our experience as social scientists co-developing a large digital library project funded by the US government. We focus here on how to understand the ways in which potential use, new and old infrastructure, and large project organization interact. Throughout, we struggle with a kind of paradox: good working infrastructure is transparent to use, yet good participatory design makes the problematics of use visible.

Information systems, unlike electricity or water, are simultaneously technical and semantic -- bits are not simply undifferentiated matter piped over the net. Additions and modifications to the infrastructure are highly decentralized and subject to dispute. There are hundreds of standards to be adjudicated. Whether the system is "working" or "not working" may be much less clear than whether or not enough "water is coming out of the tap." No one, in short, is in charge of large-scale information systems. No one has an overview; there is, in fact, no overview to be had (Hewitt, 1986).

After over one year as social science partners on a large information infrastructure- building effort, we are struggling to understand how these complex degrees of coordination and interpretation involved come to work together, when they do. In this, we are linking the historical work on the building of infrastructure (Hughes, 1989; Bowker, 1994a and 1994b, Bowker and Star, 1994; Desrosières, 1993) with the ethnography of technical design (Forsythe, 1993; Henderson, 1991a and 1991b; Suchman, 1987; Bucciarelli, 1988 and 1994) and the sociology of scientific knowledge.

Articulating a large infrastructural project within a globally changing electronic infrastructure is no easy matter. The challenge for us is no less than simultaneously to understand the work practices of designers and users, the emergence of large-scale technical systems, and the encoding and decoding of information, including its heterogeneity and disputed character as well as its conventional aspects.

PROJECT BACKGROUND

In 1994, as part of its commitment to the National Information Infrastructure (NII), the US government funded six digital library projects at different universities (under the Digital Library Initiative, called "DLI" for short). The projects range in topic from geographical information systems to general navigation tools for full-text retrieval. Eventually, it is hoped that the projects will form the basis

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for the conversion of substantial public library resources into internet-accessible format. Our project at the University of Illinois, "Building the Interspace," is geared toward engineers and computer scientists, and developing protocols for federating repositories of data. The project is geographically distributed across the (large) campus.

Within our effort in Illinois, there are several subprojects, each with differing foci. The Testbed Team is constructing working prototypes of an on-line engineering library, eventually to migrate to the web. The contents of the testbed is voluntarily supplied by publishers. The National Center for Supercomputing Applications (NCSA) is developing architecture for public repositories of electronic text and navigation. The Interspace Team is developing next-generation protocols and smart thesaurii for the transfer of information across federated repositories of data. The Administrators of the project are from yet other departments.

Our Social Science Team studies potential and actual use of prototypes, and of the web, and how engineers' work will be impacted. We have a commitment to a 3-way relationship between users, designers and social scientists, generally following the precepts of participatory design. We attempt to fit our formative evaluation work to the ideal of this method: close contact and communication between designers and users via a series of mutually-generated, iterative prototypes, continuously modified for the best fit to the target workplace, and acting as a means of communication (Bødker, et al., 1991; Ehn, 1988). We conducted usability studies with the emergent testbed, plus observations of current library users, focus groups with potential users, and interviews with faculty, students and staff. However, we had difficulties in fulfilling what we saw as our role in participatory design. Project communication was not often clear or straightforward. Sometimes it was hard to either define or find the prototypes or the content of the system. We hope this paper will be helpful to project managers and others working in the participatory design tradition or similar venues. The material in this paper draws primarily on interviews done with project staff and with university faculty and other potential users.

Good working infrastructure is almost invisible to the user: ready-to-hand, transparent, and quietly supportive. Star and Ruhleder (in press) define the qualities of infrastructure in the following fashion:

- *Embeddedness*. Infrastructure is "sunk" into, or inside of other structures, social arrangements and technologies;
- *Transparency*. Infrastructure is transparent to use, in the sense that it does not have to be reinvented each time or assembled for each task, but invisibly supports those tasks;
- *Reach or scope*. This may be either spatial or temporal -- infrastructure has reach beyond a one-off event or one-site practice;
- *Learned as part of membership*. The taken-for-grantedness of things and tools infrastructure is a *sine qua non* of membership in a community of practice (Lave and Wenger, 1992). Strangers and outsiders encounter infrastructure as; new participants acquire a naturalized familiarity with its objects in order to become members- leading directly to the following:
- *Links with conventions of practice*. Infrastructure both shapes and is shaped by the conventions of a community of practice;
- *Embodiment of standards*. Modified by scope and often by conflicting conventions, infrastructure takes on transparency by plugging into other infrastructures and tools in a standardized fashion;
- *Builds on an installed base*. Infrastructure does not grow *de novo*; it wrestles with the "inertia of the installed base," and inherits strengths and limitations from that base;
- *Becomes visible upon breakdown*. The normally invisible quality of working infrastructure becomes visible when it breaks (p.4 of manuscript).

Each of these criteria has repercussions for people's work and understanding, and for the overall project. We examine the multi- dimensionality and multi- culturalism in building information infrastructure. From the viewpoint of participatory design, our hope here is to offer a set of conceptual tools with which to understand the building of emergent infrastructure. Projects of this sort involve not only a division of labor, but also a division of knowing; they may also be said to involve a division of dreams and visions.

WATSON- VERRAN'S "IMAGINARY": CREATING A META- LANGUAGE

What is the most successful outcome of the DLI?

World peace. It sounds like a Miss America question. I don't know. On a big picture scale, I would say that the scientists, around the world even, not just ethnocentrically in the United States, are able to communicate better and not do as much competitive work, in that they rely on each other for what they are doing so that they enhance their own work. And hopefully bring... enable some leapfrogging as far as underdeveloped nations. Doesn't that sound like a world peace answer? (Testbed Team Member)

Although the nitty-gritty of budgets, code and copyright negotiation is critical to the DLI effort, dreams and visions must also be meshed. Watson- Verran's analysis of the relationship between Australian farmers and Aborigines gives us an important tool for linking visions. She describes the whole material-cultural field of the different worlds, from working to dreaming. Linking these *imaginaries*, as she calls them, means that both come to understand each others' dreams and practices. Traditional Western science has often emphasized only issues such as the quantification of land areas or land ownership, "Through our practices of quantification... we know and own land, maintaining the myth that knowable space is at once

ordered and empty. An outcome of this is that all space is equivalent; a uniform grid." (p. 16 of manuscript). Aboriginal representation of space, which includes a recursion of kinship relationships and the particular local relationships each person has with the land means: "The words of the song which celebrate this imaginary are not memorized. It is the general picture of the network of places and their interconnections that is memorized. This is a complex set of spatial images, a 'cognitive map' which can be understood as quite analogous to the Western imaging of qualities in material objects ... analogous to the infinitely extending line of integers." (p. 18) She notes (just as in the DLI): "It is knowing the 'map,' which we can understand as a matrix of vectors with each place defined through relations of varying intensity and direction, and coming up with metaphoric insights to express this map in performing songs and stories, that is valued as Yolngu intellectual work. There is a correct 'map' which everyone knows in greater or lesser detail, but the 'map' may be expressed in more and less elegant ways" (p. 18). Watson-Verran argues that the Aborigines have much to teach us about the co-constitution of "map and territory:" "The people and the land come into being together..." (p.19).

Common metaphors can be used as points of understanding, as well as for building a piece of information infrastructure. We kept thinking of different metaphors to describe infrastructure. In trying to understand the course of self-erasure we thought of the monster as it rises and falls at the surface of the Loch Ness. In thinking about the installed base, we imagined a game of Tetris, new pieces (hopefully) fitting quickly into old. To talk about multi-dimensionality and interconnectedness, we thought about textures in different bits of cloth making up a patchwork quilt. This very search for metaphors, shared by all project members, is indicative of the search for a shared imaginary. Below, we discuss some of the ways this is practically organized, and where a shared imaginary would benefit our common project.

CENTRAL CONCEPTS: COMMITMENTS, OBJECT WORLDS, TRAJECTORIES

There are three central questions facing the builders of infrastructure which also impact designer- user relationships: 1. How do individuals come to make commitments to systems building projects, and on what basis? Becker's model of "commitments and side bets" illuminates this issue. 2. How can working systems builders find both interesting technical problems to solve and build a sturdy, usable piece of infrastructure? Many have noted (e.g., Star and Ruhleder, in press; Weedman, 1995; Markus and Bjorn-Anderson, 1987) the different incentive structures between designers and users and its impact on system development. Bucciarelli's "object worlds" concept explains more about this tension from the design point of view. 3. Since pieces of infrastructure, project members' problem solving, user's skill, acceptance, and problem spaces are all moving at different rates of development, how may they be coordinated while respecting the rhythms of each? We use here Corbin and Strauss' concept of "trajectory," drawn from the work and biographical setting of chronic illness and care. In the concluding section, we show how these are interrelated.

Commitments and Side Bets

How and why does a person commit to a large project? The article we use here, Howard Becker's "Notes on the Concept of Commitment," tries to explain the shape and consistency of a person's plans and actions without relying on the popular concept of psychological motive (1960). Becker presents a theory about how someone comes to enact plans as part of an organizational and biographical landscape, where multiple contingencies and guesses are as much a part of the act as what might later come to be retrospectively reconstructed as unproblematic motive-plan-outcome. His paper foreshadows Suchman's famous discussion of "situated action" (1987), perhaps not surprisingly, since both are arguing against a cognitivism which would place planning abstractly in the mind of an individual.

Becker's landscape requires negotiation and enticement of others in order to make a successful plan work. This often involves not just direct recruitment to the scheme, but tangential or linked stakes as well: "The committed person has acted in such a way as to involve other interests of his, originally extraneous to the action he is engaged in, directly in that action." (1960:35). An action becomes "consistent" as those things which are piled up onto the plan begin to take on increasing importance: "The consequences of inconsistency will be so expensive that inconsistency... is no longer a feasible alternative." (1960, p. 35).

So, for example, someone who is *post facto* committed to a religion has over a period of time mingled friendships, career possibilities, social networks, recreation, hobbies and perhaps romance in with the original ideals or beliefs. The notion of dedication is a composite of all of these things over time which shape the actions -- one did not join the church strictly in order to meet a mate, but that was a *side bet* in the joining, and once it occurred, added another element to the commitment to the religion. No side bet, and therefore no commitment, is absolute -- they are always valuable within some specific group:

> "Many sets of valuable things have value only within subcultural groups in a society and that many side bets producing commitment are made within systems of value of limited provenience.... These esoteric systems of value must be discovered if the commitments of group members are to be understood." (1960, p. 39)

The key to good project management is precisely understanding these "esoteric systems of value" and the nature of the commitments they encompass. Failure to do so means project failure (see Weedman (1995), for an elegant analysis of this).

Within the DLI, one encounters a maze of subcultural side bets and multiple commitments, some of which are cohering into a larger group commitment, and some of which have not yet (whether they will or not is an empirical question). Each of these side bets adds

uncertainty to the larger project as a whole, on practical and ideological levels:

> *On this project you just don't see people very often. So that is different. The other difference is that this isn't any body's real job. At {another job} that's all we did, and here it is just what everybody is doing for like a third of their life or something. So that makes it more amorphous than a real world project... because there, in the real world, it is something that people* have *to sit down and think out. (Social Science Team Member)*

In addition to the "side bets" in the form of how central the project is to someone's career, another important component is how to judge and count on others' side bets. Each person or group has to make their best guess as to the intentions, goals, and priorities of the other groups, which may not be well defined with the groups themselves. Judging this complex interdependency is part of everyone's work on the project.

Multiplicity of Commitments

Infrastructure building is about designing linkages between multiple groups, making connections between many people, their world views, and their goals in order to make strong connections to extant infrastructure. In the case of the DLI, funding agencies, publishers, software developers, librarians, and users all need to be brought together. In addition, while the project should build on an installed base, the infrastructure is also extending into the unknown. Each of these different groups has their own interests and idea of what this unknown will be, and their needs ideally should all be met.

The DLI has a dual nature which is difficult to get a grasp of: it is both research and production of a working system. As one of our respondents pointed out:

> *I think part of the problems we have defining this project are due to the sort of schizophrenic demands made by NSF/ARPA/NASA in funding the six projects. The funders specified that there be a testbed component to each project .... and a research component and an interconnectivity component. All the projects are trying to better understand the testbed vs. the research component question. And NSF/ARPA/NASA themselves still seem fuzzy, at best, about the mix of testbed and research and evaluation and linkage. (Testbed Team Member).*

The publishers as well have their own set of interests. They provide SGML tagged text to the Digital Library on their own time, in return they want to learn how this process of producing digital, searchable text can be done. They are giving their materials to the Digital Library free of charge, but will not allow their journals to be displayed if the formatting of the text is not to their specifications. Negotiations hinge on mutual need, but the publishers are not obliged to cooperate:

> *What about the publishers? Are they pushing the project in any particular direction?*
>
> *They all have their own vested interest and they have got some specific goals in mind. Most of them have the same goals in mind, but we are really working in the same direction they are. (Testbed Team Member)*

A significant part of the project is about juggling the specifics of the tasks at hand. The building of infrastructure is about grafting that new infrastructure onto the old. Multiple trajectories of old and new infrastructure must come together in time and space somewhere in the future. This involves guess work and prediction, requiring tools that are new and unstable, "bleeding edge." Team members negotiate with software developers for important functionality, but which may not have highest priority for the developers:

> *They have had enormous problems. It is very difficult to render scientific journals and put them on the screen. It is not easy to index them, as it turns out. And I think we have a very solid schema for doing this, it is just a matter of getting these recalcitrant software packages to work. A lot of this is outside of our control. We are relying, in a lot of ways, on commercial packages. And these are bleeding edge software packages and we are actually trying to take some of them and paste them together. And it is kind of like handling play- dough. (Testbed Team Member)*

Thus the work of building infrastructure is about mediating demands of multiple groups and making connections between them possible. Additionally, it is about having a vision of where, in the future, all of these multiple trajectories will come together . The building of infrastructure is based on a certain amount of gambling. Investments in software, in standards, in a vision may or may not prove unfounded:

> *What is a failed DLI?*
>
> *That the whole world takes off in something other than SGML? That would probably be a big, major failure for the DLI. But since the other projects, the other groups are working on... the majority of them are also working in SGML, I would say that is not likely to happen, but.... I don't know. (Testbed Team Member)*

Everyone in digital publishing efforts at this moment is concerned with how large-scale "side bets" will play out: which markup and information interchange languages will become most widespread, and what effect that will have on current investments in computers and people's skills.

Object Worlds

Bucciarelli's *Designing Engineers* (1994) defines the "object worlds" within which engineers work, and analyzes how the ways that the fixed, reductionist, and Platonically ideal aspects of those worlds interact a) with the open-endedness of design, b) others' object worlds with whom engineers interact, and c) the life of the organization. Because engineers design things that work, their practice is materially oriented toward what Bucciarelli terms "object world thinking" :

- *Deterministic.*. Everything must be accounted for, and closure obtained.
- *Abstract.* Objects are shot through with mathematical and scientific abstractions.
- *Cause and effect chains.* Things act upon one another, and these actions are framed as casual stories for communication in the design process.
- *Measured terms.* The terms of practice are mediated by instruments; design actions can be quantified.
- *Conservation.* This is a central value; parsimony and bounds and limits on the measure of things is crucial for good design.
- *Hierarchical.* Work is structured hierarchically so one knows *where* to work, the rest is black boxed. (p. 83-86)

These qualities are mediated by an iterative process of consideration and refinement, which Bucciarelli conceptualizes as a matrix: "After the matrix has been filled once, the team reconsiders each option in turn and, focusing on those criteria that are poorly met, tries to reformulate the option to eliminate its deficiencies." (p. 152)

However, he notes, neither the list of object world characteristics nor this ideal inductive process become fully realized design. There is no absolute starting point for the matrix, nor any absolute closure. Rather, it is an iterative, practice-based process, and:

> "The object is certain, determined, abstract, conserved, and so on. The process of designing is ambiguous and uncertain; there is the unknown. Ambiguity and uncertainty are especially evident at the interfaces where participants from different object worlds must meet, agree, and harmonize their proposals and concerns." (p. 188)

As Henderson has explored in her linkage of "conscription device" with "boundary object," tools such as engineering drawings or requirements both specify and serve multiple, even conflicting purposes (1991a and b). We have found precisely this tensions, and the iterative traversing of the matrix described by Bucciarelli, in our work with the distinct DLI teams. While the project is cooperative, the organization of the project is more along the lines of a loose federation. This DLI project member describes his understanding of the relationship between the separate teams:

> *You see the DLI as a big pie with little slices.... is there a goal that all the slices hold in common?*
>
> *We are all very interested in similar issues. We would all like to bring information systems... of what ever stripe, to people in general. They are different flavors, which normally predominate. Typically in technical realms, you make these minute, hair-splitting differentiations between the technical issues you are dealing with and you talk less about the fact that indeed, we are all more or less using or going toward the same goal. The technologies dominate in the discussion. So I would say we are all going to the same goal, however the methodologies and the techniques we are using are so different that they make us look separate and we are functionally separate in that sense. (Interspace Team Member)*

Multiplicity of Object Worlds

Typically each engineer has his or her own specific interest in a particular, singular design problem or thing. This is not so in the world of building infrastructure. There is much more space between team members and between teams. The scope is greater, as it is bringing together the object worlds of many groups, embodying their standards and practices.

Thus the unity of infrastructure building project is much looser than one focused on building a thing. Each team in the project has different "objects" that they are focusing on; these many different foci and building projects revolve around one generally defined goal. Rather than an "object world" we are dealing with an "object *universe.*" For example, within the DLI, the Testbed Team is working on the construction of a working prototype of a system that indexes and searches the full text of scientific journals, the Interspace team is interested in long term information system architecture, the Social Science Team wants to look at broader implications of the information age that we are moving into. The NCSA group is building special repositories, and the Library School is developing new systems and labs for use in this university. The interrelationships between all these are difficult to get a grip on:

> *There are several distinct chunks in the DLI, but they all have a relationship to each other. Obviously if we don't build the testbed, you can't do the sociological research. And if we don't design some of the software that enables us to convert some of the scientific communications that include illustrations, equations, as well as text. If we don't design and build the software to convert that, then we can't build the testbed. So there are separate and distinct chunks but they have a relationship that come together in the overall project. (Administrator)*

The center is difficult to hold, and individual team members usually do not have an overview of the "universe" and their place in it. They are restricted to their own object worlds.

> *Explain the different components of the DLI?*
>
> *I am sure it does have components, but I am really restricted in what I am exposed to. I haven't really been exposed to what is going on with the Interspace section or you guys [the social science team]. (NCSA Member)*

Team members deal with this uncertainty by focusing on the particular object that they are responsible for.

> *I found myself working on little widgets like the keyword list and the keyword in context list and basically still sort of coming up on the learning curve*

of Visual Basic, learning how to access databases and manipulate data and those kinds of things, while still building some tools that are quite interesting. And then in January, I started tinkering around with thesaurus displays; there was me off doing my own little thing... (Testbed Team Member)

This looseness and variety in focus can be problematic when teams are supposed to be coordinating work and cooperating together. In an object universe, people don't have that single object to hold in common and to create shared understanding and vision. Problems include some frustration in not only communication but in vision for the project: *This project is extremely disorganized, and resources haven't been allocated properly. We have had a lot of battles over that and.... I am not sure everybody is on the same page in this project. (Testbed Team Member)*

In addition to the diversity within the project, connections are also being created and maintained with other collaborating and cooperating groups. The variety of groups being brought together in the space of this project is large, and each of these groups has their own interest in the project.

Sponsors want to see their money well invested in answering open questions about the nature and construction of digital libraries. To follow up on their financial support, they visit the project to see demonstrations of what has been done. Their nudging has varying levels of specificity and practicality for the project. Their focus is on the DLI as a whole and the interconnections between the different parts of the project, and even beyond that to national implications of our work.

The publishers expect the DLI to facilitate their introduction to the world of electronic publishing. The project is supposed to be able to answer questions for the publishers in terms of feasibility and usefulness of electronic publishing from the publisher's point of view. They are particularly interested in the testbed development and the displaying of their articles.

Finally, the DLI has different implications for each of the campus groups involved. For the University Library system, it is a testing ground. Their object is in learning about collaboration on this campus:

Well, there is a broader objective here. From a campus perspective, the DLI is a direct illustration of the collaborative environment that we have on this campus. Where the major units of this project have not been brought together just for this project. We have a natural relationship to each other. A successful DLI will point out the collaborative environment we have on this campus. Now a failed DLI will show some limitations in that collaborative environment and will question the effectiveness of the Grainger labs as an instrument for the development of the University Library. So that is looking at two different levels. (Administrator)

For NCSA, it is a chance to work on developments in repository building and a chance to stretch the operations of Mosaic. For the individuals working on the project, the DLI ranges from being just a job and another line on a resume to being an extension of a career path that was begun twenty years ago in library automation.

As Watson- Verran (1994) points out, the way to bring these multiple object worlds together into a shared object universe is through flexibility; imaginaries and metaphors are used to translate between object world views. The attempt to bring so many dispersed and varying views and foci together in one unified project necessitates a lack of specificity which is achieved through the shared imaginary or all the diverse views and groups cannot be accommodated.

Trajectories

A trajectory is an analytical tool developed by sociologists Strauss and Corbin (Strauss, 1993; Corbin and Strauss, 1988) to describe the temporal shape of courses of action and events. Originally borrowed from engineering as a metaphor (for example, the trajectory of a bullet through air), it has a dual nature: "(1) the course of any experienced phenomenon as it evolves over time (an engineering project, a chronic illness, dying, a social revolution, or national problems...(2) the actions and interactions contributing to its evolution." (1993, p. 54) Complex phenomenon do not just "unfold" or "emerge"; they are collective accomplishments which are refreshed in the shaping.

Different aspects of the trajectory may have different rhythms or directions, and pull on each other. A fast-moving disease trajectory pulls the biographical trajectory metaphorically "down"; on the other hand, positive events in the family may pull the body's trajectory (even temporarily) "up." A career may be unaffected by minor troubles, or effects may be delayed by an individual's determination or dissembling. In the DLI:

Panorama {a piece of software used in the testbed} is another problem. We have a shopping list of 10 major items that they have to have done before some of these publishers will let us show their journals to people. And we have been waiting all summer for them to get any of these 10 items done, and right now they have not.

What will you do if they don't?

Well, we talked the other day and we have a plan now. As of 2 days ago, we have an alternative display format that we are going to start working with. (Testbed Team Member)

Here, modeling others' trajectories and projecting into a mutual future becomes part of the project articulation work.

Multiplicity of Trajectories

As with commitments and object worlds, trajectories are also multiple. Respondents refer to the trickiness of timing as unknowns multiply:

With the different production constraints and the different sorts of database constraints, all finding a solution that works together. Getting the distributed repositories to work together and getting them to work together in a production mode where they can be continuously updated without having to have a lot of downtime. That is a lot of details that have to come together. (Interspace Team Member)

Team members must juggle and guess about variety of others' trajectories. The obvious difficulty in this is enhanced by that lack of overview, common understanding and vision: *Do you think the users should be playing a greater role?*

No. Because we are in such a testbed stage right now. Maybe in 6 months. (Testbed Team Member) Part of the guess work in trajectories is understanding the different role that each team plays. As this team member says, according to his understanding of users, they can't fit into design work until the testbed is a robust and functioning entity.

Creating information infrastructure means first forecasting what will happen in the future, then shaping the trajectories of work to converge at some future point. For example, in our project, the Testbed Team has chosen to do their work on IBM PCs and in Visual Basic, but no other parts of the project work on these machines or in this language. Translations of data must be made from where the journal articles are stored to where they are displayed; the interface must also be rewritten for the web. Juggling all of these in real time, situated daily practice is difficult.

TOWARD BOUNDARY INFRASTRUCTURES

Multiplicity is inherently important in understanding a project of this nature; many individuals and subprojects work both in parallel and serially. Concepts as "critical path," often simplify this picture. Critical path, for example, gets at the notion of coordination across divergent temporal trajectories, but does not represent the tension between front stage and back stage issues (Goffman, 1959). That is, for competitive reasons, people may not *wish* to reveal how far along they are, or make public the embarrassing mistakes along the way. Critical path may not take account of how people make and break promises based on mutual understandings of limitations and ambiguities (see for example the critiques of Winograd and Flores' (1994- 1995) "Coordinator" system).

A working infrastructure consists of thousands of such arrangements, where both ambiguity and structure (often in the form of standard) is afforded. Döpping and Bowker have coined the term "boundary infrastructure" to describe how these tradeoffs between ambiguity and standardization are managed in nursing work (Timmermans, 1995; Neumann, 1996; Bowker, Timmermans and Star, 1995). Interestingly, the success of infrastructure comes in its self-erasure or invisibility:

Do you have an influence over the outcome of this project?

No, not the final product. I am involved in the intermediate products that have to work at a certain rate within certain error limits or that will effect the final product. I don't decide the final color that the menu comes up in... I think it is important, but it is one of those deals where you know you have done your job right because nobody will notice. (Testbed Team Member)

In watching the project develop, we get a peculiar sense of the Janus-faced nature of infrastructure: the different parties need to coordinate, cooperate, and have a good sense of each other's "inner workings", and the need to have the project represent different things for different audiences, which is only possible through ambiguity, flexibility, and invisibility:

What comes next in this project?

The software stuff I think is going to continue. I think there is basically, an unlimited amount of stuff to be done to provide systems to support the DLI as a production system. I know I don't have enough time to do all that and there are not enough resources dedicated to it. If you talked to someone about doing all this stuff, they'd say "well, this is a research project" so it is sort of a two faced project, what ever is convenient. You can call it a research project when things are klugey and then there are times when you call it a production system when you are not really doing research. That is kind of handy. (Social Science Team Member)

The concept of boundary infrastructure begins with the notion of "boundary objects" developed by Star and Griesemer (1989). These are those scientific objects which satisfy the informational requirements of several communities; they are both plastic enough to adapt to local needs, yet robust enough to maintain a common identity. They are weakly structured in common use, and become strongly structured in individual-site use

Boundary objects are good at describing medium-to-long term arrangements with some stability. Star and Griesemer conceptualized more wide-spread linkages between multiple boundary objects; systems of boundary objects, which as well have the characteristics of infrastructure (more fully developed in Star, 1994).

We conclude this paper with a focus on some of the *processes* involved in crafting boundary infrastructure, returning us to our initial questions about scalability and the use of participatory design in building infrastructure.

Crystallization

Corbin and Strauss call "crystallization" (1988, p. 85) those moments where the individual realizes clearly the direction and shape of a trajectory. They cite the experience of a patient who was paralyzed from an automobile accident, "who, when he first encountered a reserved parking spot for the handicapped, suddenly realized: 'The sign, I don't know, crystallized things for me...down to a little cold hard place inside me that said -- This is it'." (Citing Nasaw,

1975:210). Crystallization is a two-phase process; at first, one realizes what performances are no longer possible; then one regroups, and projects a new future.

This process happens as DLI researchers encounter constraints (of funding, of standards), crystallize their vision of what is now possible, then move on to reconceptualize. Trajectories of work and decision making come together in a crystallization point and then move on from there. This often means settling a negotiation about a particular point such as a software package, language, or standard; for instance, the choice of Panorama as the software to display the scientific journals. Panorama is not in a final version. The testbed needs certain features to display articles; Panorama developers have a mass market to satisfy; everyone is working on limited time and resources. The difficulties now being experienced with Panorama will be settled through negotiation between the software developers, the Testbed team, and the publishers. With consensus, display, compatibility, time investment, and an agenda for further work will be crystallized. The difficulty is in predicting and coordinating these crystallization points:

> *... in terms of the technical efforts, I see three. I see the testbed effort, I see NCSA and I see the research team, which I am a part of. And I have to make sure that these different components, at the critical time, they have to coalesce, that they will in fact coalesce... that the repositories, the semantic retrieval facilities- that is the thesaurus and the ... concept space, and the full text indexing will all work together. (Interspace Team Member)*

While project members are aware that this needs to happen, no one is very clear on how or when the coordination work will take place. As ambiguities for each team multiply, these crystallization points become ever more difficult to obtain.

Grappling With the Inertia of the Installed Base

One of the greatest challenges in building infrastructure is the installed base and its inertia (Monteiro, Hanseth and Hatling, 1994). How to deal with the extant infrastructure yet innovate and project into an uncertain future?

The testbed team often deals with contingencies and problems that arise out of problematics associated with this. For example, the project depends on publishers to mark up articles. SGML is not yet a "real" standard, and the testbed has to deal with variations in what they get from the publishers who are learning as they go, so that they can make the testbed measure up to paper journals and satisfy publishers. This causes major slowdowns and thus coordination problems with other teams. True cooperative design in this situation is difficult. The testbed is struggling to make a workable prototype *and* aiming at a moving target.

Even so, in something of a contradiction, the work of the individual team member lies as a relatively certain path before each person. Team members have a fairly clear idea of what they will be doing in the upcoming months and even a year. Team members can visualize and understand small parts of the overall project quite well, but the greatest difficulty lies in figuring out how these small parts will come together.

Finding "Users"

The Social Science Team's responsibility to study and work with users, and our goal is cooperative design. But -- who *are* the users of an unbuilt infrastructural system? As discussed earlier, the testbed is in a constant flux, for example, a new computer science professional organization agreed to supply SGML tagged articles, and thus we are suddenly no longer studying electrical and computer engineers but computer scientists. As well, the envisioned users of the testbed change- are they library users or researchers in their offices? These shifts made it impossible for us to begin an intensive, ethnographic long term study of a particular group of users.

The testbed, as one user points out, is "a leap into the unknown. No one has ever tried this before." The prototype is a collage of beta version software that designers have been adapting. It is not robust enough for anyone, much less the unskilled "user," to touch. For this reason, it seems obvious to the testbed team that cooperative design and early user feedback is not possible. But when the system is "robust" the problematics that users could give feedback on have become invisible and immobile. The only change possible at that point is surface level.

> *Do you feel that the users influence decisions you make?*
>
> *At this point, no. At this point, we are still building the capability to have a meaningful relationship with the users.*
>
> *Do you feel the decisions for and the time to interact with users will be after the testbed is built?*
>
> *Yes. Yes. In a sense the people who are involved in developing the testbed you might call informed users. We are all users, including those people making the system. (Testbed Team Member)*

Closely intertwined with this issue of user ambiguity is that of the differing meanings of the project as a whole for the people working on it. For some, there will be no real users of the system; they see the project as pure research. From this perspective the difficulties encountered with beta software and publishers' articles are not sources of frustration but of new information.

For others, they see the project as aimed toward producing a system that will contain X number of tagged, indexed and viewable documents, to be used by N users. These people are concerned less with answering research questions and are more concerned with building of a viable and stable production system. These people feel the project is user centered, although cannot be directly so just yet.

These conflicting views play out in different and interesting ways, but most obviously when people talk about the

system and what it has to do with users, and following that, what the role of the Social Science Team is.

IMAGINARY AND METAPHOR: AIRY INTEGRATION

Every cultural or ethnographic study of engineers and systems designers has alluded to the aesthetic pleasures of building and their visionary. It is important to recenter the imaginary of engineering and systems development, as Watson- Verran suggests. The developers we work with *see* webs information, as they talk one can almost "see" the World Wide Web. "Seeing" this map in more detail, imaginary intact, would mean an evolving project infrastructure that affords multiple metaphors and dreams as well as standards and protocols.

These metaphors could be used as tools; managing ambiguity, very complex multiple contingencies, in a distributed and open-ended project is at the heart of crafting infrastructure. The point is to recognize necessity of communication and imaginary. As in the case of Watson-Verran's "mediation" of a land dispute, a meta-language, even for imagination, needs to be negotiated.

A lesson can be taken from Campbell's (1986) analysis of disciplines. One of the difficulties in academia specialization and isolation. While this is sometimes useful, it is often dysfunctional. Campbell calls for a "fish scale" model, where interconnections between schools of thought are easier because people are no longer sticking to a narrow specialty.

Lacking a crystal ball, we cannot predict the project's outcome, but it is at this stage "appropriately" messy and confused given the scope of problems. What we do have at this stage in the project, in addition to multiple commitments, object worlds and trajectories, are partially overlapping visions, dreams, and senses of "the whole." Each of these holds some part of our project as a whole, and none is embodied in one person. As Hutchins (1995) and others have pointed out, we need to recognize such loci of knowledge as the whole project, our practices, and the materials we use. "When these have been assimilated, the locus of "truth" and "knowledge" will have clearly shifted from individuals "minds" to a collective social product" (Campbell, 1986).

Infrastructure building is different from more self-contained, object oriented projects in linking so many communities. In order to build on the installed base, they require more strong, tight connections to the outside world. It means making the larger network active participants, in turn resulting in more interdependency. And once again, our paradox: the end product of infrastructure projects is ideally invisible, transparent usefulness; thus the foci of infrastructure projects is often invisible and difficult to articulate, having no common language. This makes the project difficult to talk about, whether within the DLI or outside.

In infrastructure there is a sense in which map and territory merge. To design something *is* to use it; there is no global testability. For these reasons, understanding commitment, object worlds and their paradoxes, and the myriad of trajectories involved is crucial. Linking them through shared imaginaries is one way in which infrastructure projects become successful.

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INFORMATION AND QUESTIONS

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