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Integrating Tacit Customer Knowledge with Internal Knowledge: In-Progress Research into Customers as Members of Cyberinfrastructure Projects

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How Do Service Providers Coordinate Knowledge with Customers? In-Progress Research into Cyberinfrastructure Projects

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ABSTRACT

This paper reports on in-progress research into the coordination of specialized knowledge for projects by "cyberinfrastructure centers" that provide infrastructural services to scientists conducting computationally intensive research. Specifically, we draw from a preliminary analysis of 51 interviews with senior personnel at 11 cyberinfrastructure centers to highlight three findings. First, members of two customer-facing cyberinfrastructure departments (Scientific Applications and Visualization) possess specialized "computational science knowledge," while members of two "back-end" departments (Systems and Operations and User Services) possess specialized "infrastructural operations knowledge." Second, the regular inclusion of front-end employees in back-end projects (and vice versa) has stimulated the development of knowledge coordination practices. Third, the need for Scientific Applications and Visualization Departments to coordinate knowledge with customers also has yielded a formalized approach in which an employee is physically embedded in a scientific project team and/or a member of a scientific project team is embedded in one of these departments.

Keywords

Knowledge coordination; cyberinfrastructure; service provision; project management; computational science knowledge.

INTRODUCTION

A rapidly growing portion of scientific research depends on access to and effective use of high-performance computing systems comprising state-of-the-art processing, storage, networking, and application platform technologies. While some of the services enabled by these "cyberinfrastructure" systems can be described as routine – executing an algorithm through a batch scheduling program remains a common service, for example – a significant number are effectively non-routine. For these non-routine services, creating value for customers typically entails the production of new source code by cyberinfrastructure center employees who work to administer, maintain, and develop the advanced systems that enable computationally intensive research.

Cyberinfrastructure centers typically frame these non-routine services as projects. A large cyberinfrastructure center may have more than a hundred active projects of this type, and each project can vary considerably in terms of its duration (from less than a week to more than a year), number of active members, and extent to which and ways in which customers (i.e., researchers) are involved. Much of this variation is a function of the project's scope: a larger project might have as a goal the development and implementation of a novel, GUI-driven application for exploring and analyzing computational chemistry data, while a smaller project might aim at re-writing in Fortran an algorithm that computational biologists wrote in a language that is not as well suited for scientific computing (e.g., Python).

Cyberinfrastructure centers typically assign a project manager to each project. As with most projects that entail the coordination of specialized knowledge from multiple knowledge domains, the cyberinfrastructure project manager must articulate the knowledge required for the project, identify the individuals who possess the requisite knowledge, and work with other managers to secure the services of these experts over an estimated number of weeks and hours. While no study to date has examined how cyberinfrastructure project managers coordinate knowledge from multiple domains, a number of studies have examined how managers of other types of knowledge-intensive IT projects have done so. In the following section we review in brief these studies in order to identify conceptual gaps.

BACKGROUND

Success in knowledge-intensive IT projects depends in large part on a project manager's ability to "integrate fragmented pockets of specialized knowledge" (Mitchell, 2006, p. 919). It is not surprising, then, that project managers spend much of their time bringing together experts from multiple knowledge domains and aiding their efforts to collaborate effectively (Hoegl *et al*., 2004). In the information systems (IS) literature, this activity is typically referred to as knowledge coordination (or sometimes knowledge integration). Coordinating knowledge can be difficult because the knowledge under consideration is largely tacit, and therefore resistant to inscription. For the most part, studies of knowledge coordination share a concern with *how* knowledge (or expertise) is coordinated across boundaries (such as knowledge domains) and with how knowledge coordination can promote success in knowledge-intensive IT projects.

In a recent review article, Hsiao *et al.* (2012) argued that there are essentially three perspectives on cross-boundary knowledge coordination: trading; sharing; and knowing. From the trading perspective, knowledge coordination occurs *through* boundary objects or "knowledge objects" (Nicolini *et al*., 2012; Kellogg *et al*., 2006) that reside within "trading zones" (Galison, 1999). Using as an example Boland *et al*.'s (2007) study of the use of 3-D representations by architects, engineers, and contractors, Hsiao *et al*. note that these actors "continually redefine and mutually adjust their relationships through the interpretation of [3-D representations as] boundary objects" (p. 465). Based on their case study of a web-based marketing firm, Kellogg *et al*. (2006) proposed that knowledge is coordinated within trading zones through three trading practices: display, in which objects are made visible; representation, in which objects are made legible; and assemblage, in which objects are revised and aligned.

A second perspective on cross-boundary knowledge coordination – the sharing perspective – hinges on knowledge as shared cognition and draws heavily from Carlile's "3T" model (2002; 2004). For Carlile, knowledge can be coordinated across three types of boundaries. Along syntactic boundaries, experts *transfer* knowledge through a common lexicon; along semantic boundaries, they establish common meanings (such as a metaphor) in order to *translate* domain-specific know-how (Hsiao *et al*., 2012). Finally, experts *transform* knowledge along pragmatic boundaries by realigning their domain's conceptions according to new, cross-boundary conceptions. The sharing perspective is implicit in several empirical studies, including Vlaar *et al*.'s (2009) case study of onsite and offshore IT vendors who employed sensegiving, sensedemanding, and sensebreaking practices in order to coordinate specialized knowledge. The third and final perspective – the knowing perspective – posits that knowledge is acquired through participation in community activities. Hsiao *et al*. (2012) argue that this perspective is the least developed of the three, and indeed we still know very little about how experts collaborate *in situ* across community boundaries.

In sum, there is a small but growing number of theories about how cross-boundary knowledge is coordinated across departments and/or partnering organizations, and each of these theories is based on one of three ontological assumptions (Hsiao *et al*., 2012). What is lacking from existing studies of cross-boundary knowledge coordination, though, is (1) the recognition that "external knowledge" can include knowledge possessed by customers and (2) empirical studies of how knowledge is coordinated across the boundary separating a service provider and its customers. Our in-progress research into knowledge coordination activities is sensitized to these omissions. Before presenting our preliminary findings, though, we first describe our empirical context, namely, the provision by "cyberinfrastructure centers" of infrastructure as a service (IaaS) to scientists conducting computationally intensive research.

Producing New Source Code for Customers in Cyberinfrastructure Projects

The term "cyberinfrastructure" refers to the advanced computing systems that enable computationally intensive scientific research (i.e., "Big Science"). Cyberinfrastructure can be understood as a layered stack of technological resources (Yoo *et al*., 2010). The stack shown in **Figure 1** comprises five layers: a base layer of hardware; a systems software layer; a programming environment (or application platform) layer; an applications and codes layer; and, at the top, a portals and gateways layer. Each layer in turn comprises multiple resources. The hardware layer, for example, includes resources associated with processing, storage, and networking. An applications and codes layer might include resources such as data analysis programs and code libraries. In sum, every cyberinfrastructure resource is a constituent of one of these five layers.

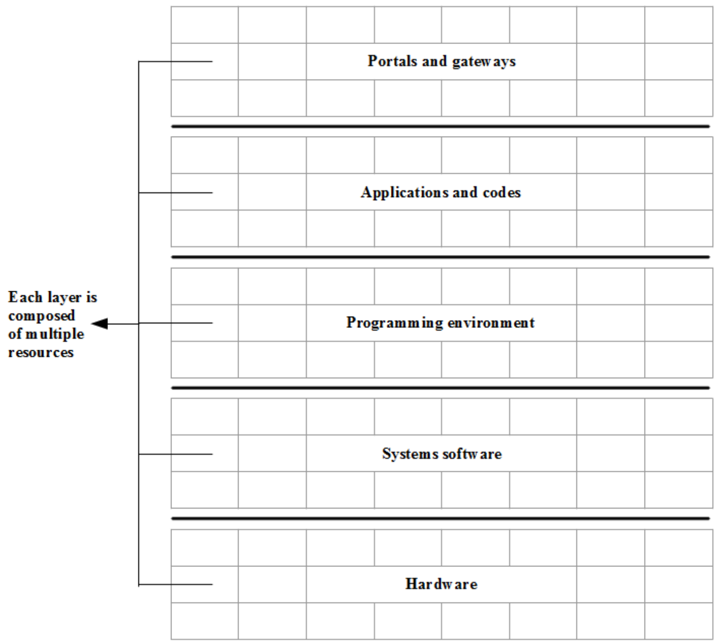

Figure 1: Cyberinfrastructure as a Layered Stack of Technological Resources

We posit that cyberinfrastructure can be understood as a *service* that cyberinfrastructure centers offer to the researchers who depend on it. While some cyberinfrastructure services are routine and mostly automated – executing an algorithm through a batch-scheduling program, storing simulation data on a filesystem, notification of job completion, etc. – many others are not. For many of these non-routine services, cyberinfrastructure centers must produce new software (e.g., workflow executables, a GUI-driven application for visualizing cellular data) or new algorithmic code (e.g., a parallelized numeric method for simulating dark matter growth). Unfortunately, a cyberinfrastructure center employee who is a computational expert in a general sense may lack the expertise to produce source code for, say, astrophysics applications. Similarly, a cyberinfrastructure center employee who is an expert in computational astrophysics may have difficulty producing source code for biology applications. Accordingly, non-routine cyberinfrastructure services – which cyberinfrastructure centers typically frame as projects – may require some level of interaction between cyberinfrastructure center employees and their customers (i.e., researchers).

METHODS

Our efforts to explore the practices surrounding cyberinfrastructure services and projects are grounded in 51 face-to-face interviews we conducted in 2011 with 45 different administrators and department-level managers from 11 different cyberinfrastructure centers. Interviews were loosely structured and ranged from 35 to 90 minutes in duration. In general, our aim with these interviews was to improve our knowledge about and understanding of cyberinfrastructure centers, including:

1 The scope of cyberinfrastructure centers' service offerings;
2 The professional backgrounds of study informants;
3 How work is organized at cyberinfrastructure centers;
4 How informants make strategic decisions;
5 Informants' prevailing perceptions about the cyberinfrastructure field and its future;
6 The extent to which and ways in which cyberinfrastructure centers work together; and
7 Everyday work practices at cyberinfrastructure centers.

Our efforts to analyze transcribed interviews are still in progress, but to date we have performed open and axial coding (Glaser, 1998) on portions of all 51 transcribed interviews. Sensitized to the conceptual gaps identified above, but otherwise not guided by any particular conceptual framework, one author's first attempt at theoretical coding yielded the working models shown in Figures 2 and 3. When the authors produce a draft of the final report, informants will be given the opportunity to provide comments. Finally, it merits noting that informant initials (in the Findings section) have been changed to protect informant identities.

PRELIMINARY FINDINGS

Drawing from the organizational charts provided to us by study participants, we present in **Figure 2** a composite model of the functional organization of cyberinfrastructure centers. In this model, a cyberinfrastructure center comprises six departments, the first four of which interact directly with customers:

- User Services, which provides basic, technical troubleshooting services to customers;
- Scientific Applications, which develops source code for and with customers;
- Visualization, which develops data visualization programs for and with customers;
- Education, Outreach, and Training (EOT), which administers structured training programs to customers and education and outreach programs to high school and undergraduate university students;
- Systems and Operations, which maintains and updates the bottom three layers of the cyberinfrastructure stack (see Figure 1); and
- Advanced Strategic Applications (ASA), which performs research and development activities.

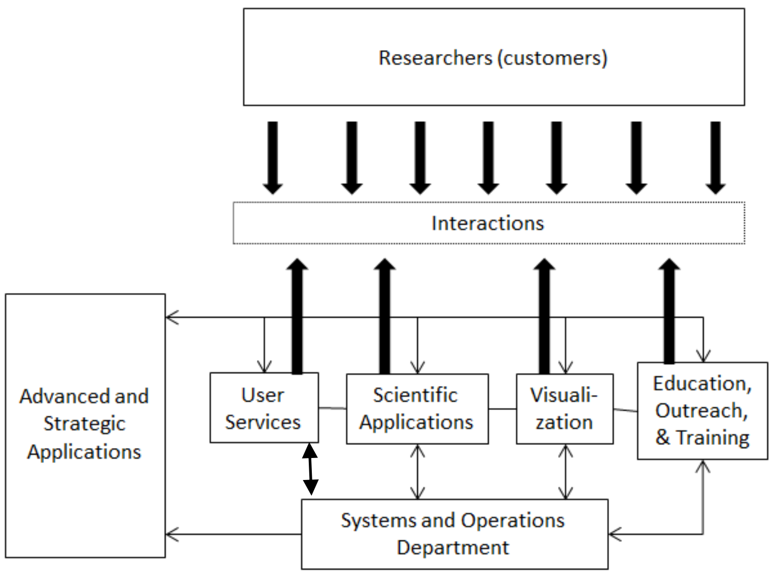

Figure 2: A Composite Model of the Functional Organization of Cyberinfrastructure Centers in Relation to Their Customers

Our preliminary analysis suggests that while each department's members possess knowledge specific to their department, a distinction can be made at a higher level between the knowledge possessed by members of the Systems and Operations and User Services Departments and the knowledge possessed by members of the Scientific Applications and Visualization Departments. More specifically, members of the latter departments possess knowledge about how to (re)write source code that yields or helps interpret or analyze scientific research results (i.e., *computational science knowledge*). Members of the former departments, on the other hand, possess knowledge about how to maintain, "troubleshoot," and optimize the (mostly invisible) resources that let the customer-facing employees do their work (i.e., *infrastructural systems and operations knowledge*).

In every cyberinfrastructure center examined, front-end employees are regularly included in back-end projects and vice versa. This practice serves not only to keep each group's members apprised of ongoing developments in the other group, but also to exploit the knowledge of the other group's members in order to advance the project. Thus, knowledge coordination is a common practice in cyberinfrastructure centers:

> *"[W]e draw on each other's groups very heavily. I pull in people from LR's group to help me when I am developing proposals… Right now we're working [together] on bringing up [a computing resource], any user issues, how applications are coming, and how the systems are growing." [PN]*

Regularly scheduled meetings appear to be the most common means by which knowledge is coordinated internally. Wikis serve as another coordination tool (*"no one updates the web site, but everyone is happy to update the wiki" [JK]*). In addition, managers try to make coordination easier by hiring people with a broad range of skills. For example, one informant noted, *"We try to look for good people who are capable of doing a variety of things. We are not often looking for a debugger person or whatever" [BB]*.

There is also ample evidence of efforts to coordinate knowledge with other cyberinfrastructure centers. One informant even refers to all the cyberinfrastructure centers involved in one large project as a "virtual organization":

> *"It's a very interesting management challenge because… these other guys [at other cyberinfrastructure centers] are responsible to their own managers, and so if I want something, I just [have to] coordinate their activities. It's really a very neat virtual organization. I have to persuade and set goals, and if I see something that I don't like [then] I have to contact the managers there and say we have a problem here." [PS]*

Project managers from the Scientific Applications and Visualization Departments also must coordinate knowledge with their customers, for it is these customers who possess the domain-specific scientific knowledge that is expressed through the customized source code or visualization. Indeed, some customers are regarded as *de facto* team members:

> *"Some users aren't users any longer. They're part of us, and we're part of them. It's a symbiosis" [AS]*.

Another informant stated that

> *"There are some [customers] that really know the machine in depth and can do everything they need to do. We learn from them" [RL].*

Figure 3 illustrates a working model of the way that at least three cyberinfrastructure centers are formalizing an approach to knowledge coordination with customers. In this model, a cyberinfrastructure center embeds an employee from the Scientific Applications or Visualization Department within a scientific project teams. (The word "embed" comes from an informant who remarked, *"I embedded a bioinformatician into each engagement team" [TD]*.) At the same time, another scientific project team embeds one of its members within the cyberinfrastructure center's Scientific Applications or Visualization Department. Most or all of the embedded individual's work time is dedicated to the collaborative project, and in most cases embeddedness entails physical co-location. Further, a review of the career histories of informants suggests that some researchers ultimately take a permanent position with the cyberinfrastructure center.

CONCLUSION

One conspicuous gap in the literature on cross-boundary knowledge coordination is the lack of recognition that "external knowledge" can include knowledge possessed by customers. The in-progress research described in this paper serves as the start of an attempt to not only make explicit this recognition but to understand how knowledge is coordinated across the boundary separating a service provider and its customers. To this end, our preliminary analysis of cyberinfrastructure projects has yielded four findings First, the prototypical cyberinfrastructure center comprises six departments (see Figure 2), four of which interact directly with customers. Second, members of the Scientific Applications and Visualization Departments possess specialized knowledge about how to (re)write source that yields or helps analyze scientific research results, while members of the Systems and Operations and User Services Departments possess specialized knowledge about how to maintain, repair, and optimize the resources that let the customer-facing employees do their work. Third, customer-facing employees are regularly included in back-end project and vice versa; accordingly, there is a project-driven need to coordinate knowledge across departments. Fourth, project managers from the Scientific Applications and Visualization Departments also must coordinate knowledge with their customers, for it is these customers who possess the domain-specific scientific knowledge that is expressed through the customized source code or visualization. At present, cyberinfrastructure centers are formalizing an approach to knowledge coordination (see Figure 3) in which (1) an employee from the Scientific Applications or Visualization Department is embedded (physically and full-time) in a scientific project team and/or (2) a member of a scientific project team is embedded in the Scientific Applications or Visualization Department.

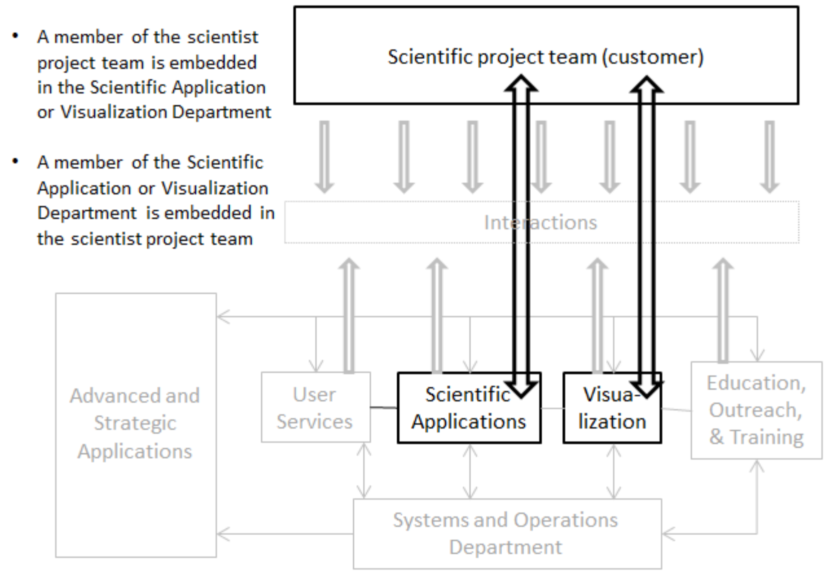

Figure 3: Coordinating Knowledge By Embedding Scientists in Cyberinfrastructure Centers and Cyberinfrastructure Center Employees in Scientific Project Teams

With regard to next steps, we will first complete our analysis of knowledge coordination activities by cyberinfrastructure centers. From this analysis we will develop and introduce a model which extends "trading" theories of knowledge coordination (e.g., Nicolini *et al*., 2012; Boland *et al*., 2007; Kellogg *et al*., 2006) by including customer knowledge as a type of external knowledge and by framing co-produced scientific source code as a trading-zone boundary object. In addition, we intend to incorporate a temporal dimension to our study in order to account for the retention and leveraging of knowledge gained over time from projects. Based on the following statement by an informant, this endeavor should be made a priority:

> *"Because of the evolution of the underlying infrastructure over time, it has become more and more appropriate to facilitate the cross-project collaboration… One thing that's clear is that [the cyberinfrastructure center director] wants to get to this situation where these projects are interoperating and leveraging each other much better." [RM]*

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