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Understanding agility in software development through a complex adaptive systems perspective

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SOCIAL CAPITAL IN DISTRIBUTED SYSTEM DEVELOPMENT: A CASE OF GRID DEVELOPMENT IN PARTICLE PHYSICS

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Abstract

This paper examines dimensions of social capital in the distributed collaborative development of the UK particle physics Grid. It is shown that the GridPP project effectively draws upon social capital rooted in the tradition and culture of particle physics experiments, characterized with trust, equality, shared vision, collaboration, and pragmatism. These factors contribute to overcoming the challenges in the creation and sharing of knowledge in the development of the Grid, a cutting-edge technology that has to be delivered as a working system with limited time and resources. This case sheds lights on, and provides a good example of, the importance of social capital in distributed systems development.

Key words: Distributed System Development, Social Capital, Knowledge Processes, Grid

1 INTRODUCTION

As systems development activity becomes increasingly globalised and distributed, projects face great challenges in developing and maintaining knowledge and expertise. The need to mobilize knowledge capabilities is particularly acute when the task itself if highly complex, uncertain, and involve innovative technologies. In this paper we use the concept of social capital to examine the knowledge processes in the development of the UK particle physics Grid. Perceiving the construction of the Grid as a grand systems development challenge in technical, organizational, political and human terms, we would like to go beyond the usual software-centric view of system development, and focus on how a collaborative project, GridPP, dynamically mobilizes social capital to sustain the distributed system development process.

The UK particle physics Grid is part of an initiative which aims to produce not just a working system but a new generation of computing technology that will potentially have significant impact on scientific research, and may foreshadow the "next generation Internet" (Abbas 2004; Carr 2005). It is being developed as a large scale distributed collaboration, by particle physicists who come from a community with very distinctive work practices and culture (Knorr-Cetina 1999; Traweek 1988). They have a record of success in developing innovative computing solutions of which the World Wide Web is the most notable example (Berners-Lee 1989).

The rest of the paper starts with a literature review which connects distributed system development and social capital. The case is then introduced, followed by a brief outline of the methodology. Section five provides an analysis of the case using the three dimensions of social capital (Nahapiet and Ghoshal 1998). Section six further discusses the implications of mobilizing social capital for knowledge processes in distributed systems development, and concludes the paper.

2 DISTRIBUTED SYSTEM DEVELOPMENT AND SOCIAL CAPITAL

With the current trend of globalization where the IT industry is becoming more and more globally interconnected (Herbsleb & Moitra 2001), information systems development has increasingly become a multi-site, multi-cultural, globally distributed undertaking (Herbsleb, Paulish and Bass, 2005). Today there are more software projects running in geographically distributed environments and the so called "global software development is becoming a norm in the software industry" (Damian & Moitra 2006). One of the advantages of distributed system development is the fact that it provides opportunities for developers in dispersed locations to build and share their knowledge collectively. An example of distributed systems development is open source projects, characterized with a highly distributed environment, collaborative and rapid development among virtual teams and rapid evolution as the environment changes (Lee, Banerjee, Lim, Kumar, Hillegersberg and Wei, 2006). Similarly, the globalization's effects on outsourcing of software production and systems development have made outsourcing take up global dimensions, and thereby become an international complex undertaking which requires a tremendous amount of support and interaction (Yalaho 2006).

As distributed system development emerges as the new paradigm in developing large-scale systems (Damian & Moitra 2006), there are still challenges and complexities involved in managing the development, such as cultural issues, communication issues and technical issues that need to be addressed (Herbsleb & Moitra 2001). Various studies have looked at aspects of managing virtual teams across time and space. Sarker and Sahay (2004) for example, identify problems experienced in distributed systems development, including those arising from geographical separation, different cultural contexts and different information systems development practices. Powell and associates (2006) similarly look at the relationship between team commitment, member effort, and trust in virtual teams as compared to collocated teams. DeLuca and Valacich (2006) examine the effectiveness of using asynchronous and synchronous media in virtual teams. In this paper, we draw upon the concept of social capital to investigate how GridPP mobilizes its collective knowledge to overcome difficulties and challenges in its large scale distributed systems development project.

The concept of social capital has been traced back to Durkheim (Portes 1998). Bourdieu (1986) identified the value of social capital in the context of unequal power relations reproduced in societies. He defines it as "the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance or recognition" (ibid. p. 248). Coleman (1988) distinguished social capital from physical capital, embodied in material form, and human capital, embodied in the skills and knowledge acquired by an individual, and sees social capital as existing in the relations among persons. Later, Putman (1993; 2000) exported the concept out of academia and into a wider media. If Bourdieu and Coleman represent a sociological perspective on social capital, Putman took a political science perspective, whereas Fukuyama (1995) integrated the concept with trust in an economic framework, and defines it as "features of social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit" (p. 57). Fukuyama's work is considered representative of the "economic imperialist version of social capital" (Fevre 2000, p.103), which is based on a rationalistic model of individuals. In organization studies, the concept has also gained considerable currency and has been applied in a wide range of topics ranging from workers' career advancement to firm strategies in a network (Adler & Kwon 2002). Adler and Kwon (2002) define social capital as "the goodwill available to individuals or groups. Its source lies in the structure and content of the actor's social relations. Its effects flow from the information, influence, and solidarity it makes available to the actor."

From the perspective of organizational advantage, Nahapiet et al. (1998) establish the linkage between social capital and collective knowledge in the organization. They argue that social capital facilitates the creation of new intellectual capital by affecting the conditions necessary for exchange and combination of existing intellectual resources, in the form of explicit and tacit knowledge and knowing capability. The linkage between knowledge processes and social capital has also been explored by information systems researchers. For example, Urquhart, Liyanage, and Kah (2008) suggest that the weaker the social capital, the harder it is for the knowledge and human capital to grow in a community. In this paper, we take the view that knowledge is socially constructed (Berger & Luckmann 1966), and that social capital draws our attention to the importance of social relationships, identities and values such as trust which facilitate the knowledge processes. Knowledge is co-constructed in a dialectic between individuals within the context of social structures (Berger et al., 1966). Individuals express themselves through language (broadly defined) which others must interpret to create new knowing (which may or may-not align with the previously known). It is for this reason that we adopt the perspective of social capital to explore practices of knowledge-construction and sharing of individuals and collectives, yet appreciating that knowledge cannot be objectified, it is always "known". Documents and information can only be potential for knowing, rather than knowledge itself.

Nahapiet et al. (1998) conceptualize three dimensions of social capital: *structural, cognitive,* and *relational* dimensions. *Structural* dimension refers to the overall pattern of connections between actors – that is, who you reach and how you reach them. Drawing upon the term "relational embeddedness" by Granovetter (1992) which describes the kind of personal relationships people have developed with each other through a history of interactions, e.g. respect and friendship, the *relational* dimension of social capital refers to those assets created and leveraged though relationships. Key facets in this dimension include trust and trustworthiness, norms and sanctions, obligations and expectations, and identity. Finally, the *cognitive* dimension refers to those resources providing shared representations, interpretations, and systems of meaning among parties (Nahapiet et al. 1998, p. 244), for example, shared language and codes, and shared narratives. The distinction between the three dimensions of social capital is for analytical purposes and they are inevitably overlapping and interrelated. Within this paper we employ these social capital dimensions as analytical devices to explore the case of GridPP, and through this explore the social construction of knowledge within this community.

3 CASE DESCRIPTION

The LHC Computing Grid is building a large-scale computing infrastructure for the high energy physics community. The Large Hadron Collider (LHC) particle accelerator at CERN, the European Laboratory for Particle Physics, is designed to collide Hadron particles at energies close to those of the Big Bang in its search for the elusive 'Higgs-Boson' particle (believed to be responsible for matter having mass). These collisions will produce data within the LHCs four experiments (ATLAS, LHCb, ALICE and CMS). The number of collisions, and the subsequent data produced by the experiments, is vast, thus finding the Higgs-Boson has been likened to searching for "a person in a thousand world populations", or for a "needle in twenty million haystacks. The LHC envisages producing 15 million gigabytes of data a year - equivalent to a DVD every 15 seconds or 1% of global information production (Lee et al. 2006). To store and analyze this data the LHC requires the equivalent of 100,000 PCs spread across the globe and working as a Grid (Economist 2005).

A technical perspective sees a grid as a computing platform for coordinated resource sharing and problem solving suitable for data-intensive and compute-intensive applications (Foster et al. 2001). In this way a grid connects and coordinates diverse and heterogeneous computing resources across space and different domains, presenting itself to users as though it was a single resource. A central concept for grids is that of the virtual organization (VO), and resource management is based on permissions for access to shared resources that members of a VO can make use of, disregarding actual hardware locations[1]. Thus the four LHC experiments are examples of VO, and allow physicists from around the globe to access data and run analysis "jobs".

The LCG has been broken down into various elements, and distributed among various countries. The UK contribution to the LCG is GridPP, a collaboration of 19 UK universities, the Rutherford Appleton Laboratory, and CERN. The GridPP project started in 2001 and has been involved in developing applications, middleware and providing technical infrastructure and storage and processing units. The LCG has a hierarchically tiered structure, with Tier 0 at CERN, Tier 1s consisting of the national IT centres in each of the major countries involved in the project, and Tier 2s being the regional centres in each country.

4 METHODOLOGY

GridPP's unique nature provides a revelatory case of distributed systems development practice (Venters & Cornford 2006). Drawing from the interpretive research tradition in information systems the focus of this study is on sensemaking and the symbolic world of those studied (Walsham 1995). The research team includes a senior experimental particle physicist to ensure that the research is not undermined by a lack of understanding of physics.

Data collection began in August 2006, following earlier pilot work, and has included participant observations of weekly project management board meetings and deployment team meetings, quarterly GridPP collaboration meetings in the UK, international meetings of the LCG, site reviews carried out by GridPP, observation of various forums and conferences in which GridPP participates. The research team has had full access to the GridPP main documentation, and we subscribe to its main mailing list and the deployment team mailing list. At the core of this research are over fifty semi-structured qualitative interviews of between one and one-and-a-half hours, undertaken at various universities across the UK and during two week-long periods at CERN in Geneva. Table 1 provides details of the

[1] Grids are distinguished from existing distributed computing in that scientists/users do not have to negotiate their use of different sites or resources separately and deal with security restrictions of individual sites, nor have to find out the precise location of their data. They need only one user-account to access a wide range of resources – processing and data – as permitted by being a member of a VO.

Table 1. Details of research activities.

Research Methods		Examples	Data Collection
Semi-structured interviews		Members of GridPP, middleware developers, members of LCG at CERN, physicist users…	Audio-recorded, transcribed, coded
Participant observations	Virtual meetings	weekly PMB meetings weekly deployment team meetings	Audio-recorded, notes taken, not transcribed
	Face-to-face meetings	GridPP collaboration meetings, PMB face-to-face meetings, deployment team face-to-face meetings,	Many audio-recorded, notes taken, not transcribed
	Site visits	GridPP site readiness review	Notes taken
Secondary data		GridPP publications, GridPP documents, GridPP website, wiki, blogs, mailing lists	Frequent consultation

research activities undertaken. Interviews were audio-recorded, transcribed and then organized for analysis using the Atlas.Ti software. We found the software useful in handling the amount of data we had, but we didn't want our thinking to be restricted by software. Rather than developing a theory from the data, our data analysis was closely integrated with theoretical development in an iterative and incremental process, one feeding into the other. Data analysis was closely integrated with theoretical development in an iterative process, one feeding into the other.

We can identify three stages of data analysis. The first round was open coding of the data, labelling aspects of the project, their practices, and emerging ideas from the phenomena. In the second round of data analysis, we used the conceptual constructs related to social capital and knowledge processes as categories to set up code families. This is similar to axial coding in grounded theory (Glaser & Strauss 1967). But these relationships were not understood as indicating causality. In this process, some codes were merged, some became more general or more specific. Not all code families were included in our analysis, as some were considered interesting phenomena but not directly related to the key concepts. This was an iterative process until the key conceptual constructs were sufficiently refined. It should be noted that we also verify the findings from the interviews with a survey, which largely confirm all the themes that we derive from coding the interviews. In the end the analysis reported here is the result of the iterative reflections and ongoing discussions within the research team and with GridPP members, rather than a narrow machine-derived account. All the quotes given here are taken from interview transcripts, and our ideas have also been reinforced by informal conversations and participant observations.

5 SOCIAL CAPITAL & SYSTEM DEVELOPMENT IN GRIDPP

In this section we examine how collective knowledge is cultivated and mobilized in GridPP. The dimensions of social capital (Inkpen & Tsang 2005; Nahapiet et al. 1998) are drawn upon to explore various practices employed by members of GridPP in the distributed and collaborative project.

5.1 Structural dimension

5.1.1 A network structure and decentralized management

Figure 1 shows GridPP's management structure which may be better described as a network than a hierarchy. The Project Management Board (PMB) is the heart of the network centrally coordinating the project. It provides quarterly reports to the Collaboration Board, consisting of representatives from the 19 institutes. The participating institutes enter the collaboration not under any legal obligation, but bound by a Memorandum of Understanding, which specifies the amount of resources and the level of

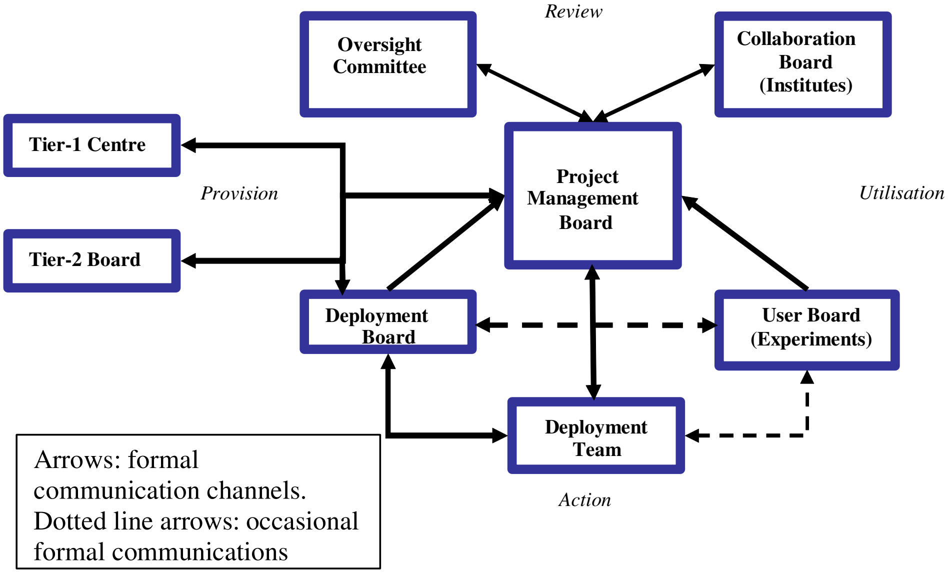

Figure 1 Organizational chart of GridPP (Adapted graph from the GridPP website)

service that each site is committed to provide, and the funding and support they will receive from GridPP in return. This document serves more as a "gentlemen's agreement" and thus there is no authoritative hierarchy between GridPP and the institutes, thus there are not top-down command lines between them. Decisions have to be made on a democratic basis and implemented by influence and persuasion.

The PMB, apart from the project leader, deputy project leader, and the project manager, consists of representatives from a number of internal and external committees, boards and functions. In a sense, the figure also indicates the external and internal environment in which GridPP operates. Due to role differences, some members of the PMB are more closely connected to the main GridPP activities than others. An important thing to note is that each of them serves as a node on this network, while connecting the GridPP to a variety of nodes on other networks that they represent here.

Associated with this networked structure of the project, members of GridPP are generally given huge reign of freedom to carry out their work, usually without clear instructions or strict supervision. When we asked them how they know what they need to do in their day-to-day job, most of them replied that they would look around and find out what needs to be done, as well as responding to arising problems and crises. "*This environment is based on, if you want, charismatic leadership and people doing things relatively independent but also having the freedom to do them, and not having to report every two minutes on what they are doing.*"

Due to the complexity and prototypical nature of the Grid, knowledge has often to be acquired in processes of exploration and experimentation. Moreover, as the technology is being developed and changing rapidly and constantly, it is difficult to keep documentation up to date. We did not observe a lot of effort in codifying and documenting of the Grid project in a structured way. As a result, most knowledge is embodied within the individual experts (Blackler 1995). Since most people in technical roles are on a contract of two to three years, there is a risk of losing expertise due to turnover. Nevertheless, the extensive communication channels within the community foster the social construction and reconstruction of knowledge through socialisation (Berger & Luckmann 1966). This focus on communication will be explored in the next subsection.

5.1.2 Extensive communication channels

Members of GridPP maintain a general understanding of the project, especially aspects related to their specific roles, through continuous and extensive communication flows in the community. Particle physics collaborations are managed by what Knorr-Cetina (1999) refers to as "a fine grid of discourse", channelling individual knowledge into the collaboration and providing it with a sort of "distributed cognition". This web of communication includes a complex network of boards, committees, and working groups which are regularly holding meetings. One of the most important methods is the online virtual meeting. During these meetings wikis, webpages and blogs are used as stores of previous communication. There are also various mailing lists where there is constant exchange of questions and answers and where solutions emerge. Members of GridPP subscribe to mailing lists relevant to their own job functionalities to keep up with what's going in the project.

More importantly, understanding and know-how of various aspects of the project are embodied in the key members of the project and carried to different clusters or groups of agents by these people sitting in various boards and a large number of meetings. Besides this formal management structure, most members of the GridPP agree that very often the more important things happen informally under face-to-face circumstances, e.g. over coffee breaks and meals, or (being a British community) "in the pub".

Such extensive communications embody mutual monitoring and proactive sense-making. This resonates with communities of practice in which knowledge is shared through their collective communication and shared sense of identity (Brown & Duguid 1991; Wenger 1998; 2000). The structure of the project, reflective of the experimental nature of the field, provides a context in which knowledge is socially constructed (and so shared) through socialisation (Berger et al. 1966). The focus of work is thus upon exploration and sensemaking, rather than upon the following (or construction) of formalized, codified "designs" or "plans".

5.2 Cognitive dimension

5.2.1 Shared goal

While GridPP does include some people from other fields, the majority (and all senior members) are from this "elite science" (Traweek, 1988) which is highly competitive to enter. One consequence is that members of the collaboration are strongly characterized by a shared common goal which is not to build a grid; but to enable the discovery of new physics and to probe the origins of the universe. This concept of a "shared goal" is frequently mentioned, and can be seen to bind efforts, solicit devotion, and bridge differences. A PMB member attributes GridPP's organisation to "*their history and the desire to sort of jointly achieve things"*. For example, despite severe competition between experiments, they will willingly work together on grid development because it is required to do new physics: "*I said I was proud of being a particle physicist, this is 'cause particle physicists always get the job done; by and large because they are driven by one fundamental thing. They want their experiment to work when the beam gets into the accelerator, okay? And that transcends everything else they do."*

The common goal of serving Physics is an important source of motivation and commitment. As a recent physics PhD graduate pointed out; "*They don't work for money of course because particle physics doesn't have a lot of money. They work because of their passion to do science. So they, we, strive to deliver the best result, to collaborate in the best way because we serve the same ideas and the same, the same passion."* Moreover, the shared vision provides a strong sense of direction, urgency and progress.

5.2.2 Shared culture

A shared culture in GridPP emerges from the physics background of most participants. The Grid project arose from the need for a tool to analyze data from the LHC; from the organizational memories of previous successful and innovative experiments; and from a history of cutting-edge computing. Moreover, it also emerges from a tradition and culture of strong commitment with a long term vision, pragmatic problem-solving and developing tools through improvisation and *bricolage*, as well as respect for individual creativity and technical expertise. As one interviewee pointed out, *"The particle physics community and the goals and the culture has had an enormous influence on GridPP… So it's not that particle physics is telling us what to do, it's just that we know it. It's the culture."*

With decades of experience running experiments, it is not surprising that GridPP is set up in the structure of a particle physics experiment and largely managed in the same way. The established traditions and accumulated experience means working in large scale globally distributed collaborations is almost "second nature". A member of the PMB commented "*I think historically particle physics has this background in teamwork and this way of working you know, a very strong background in that.[…] When I started off in experiments, there were about 20 people in an experiment, and now there's 500 in the current experiment, ATLAS probably 2,000. So that […] we've all worked through this, of adapting to that sort of way of working, which is the sort of thing of course the Grid introduces, international projects, um, large scale resources, worldwide. So it's sort of second nature I think…"*

5.2.3 Norms

In face of the high level of complexity and uncertainty that GridPP faces, compound with limited time and resources, the way they do computing has to be very pragmatic and often on the basis of trial-and-error. In a project with such as a multitude of hardware and software elements, no one person can have a clear idea of the whole system; requirements cannot be pre-specified in detail; architectures are often conditional conjectures, and technical decision-making is emergent and empirical. As a result, GridPP has to be constantly adapting to changes, and practices in GridPP have been described as "ad hoc". The PMB focused on accommodating change as their minimal planning process. "*So we set up this project map and …the formality of change forms. So this was to formalise our freedom to change the project … yes, we had a set of milestones but you know, we had a mechanism to change them because we have to be responsive."*

Pragmatism is one the norms dominant in the particle physics community. Which is not only reflected in computing, but has roots in physics experiments as well: "*not just in GridPP but in building hardware and building detectors - all sorts of setbacks occur and you have to find solutions. Certain technology doesn't work, the company cannot provide what you want. So I think there's this background in problem solving and project management and the sort of pragmatic approach*".

This caused friction with the computer scientists working in the project, most of whom aspire to a more methodological approach. A technical expert commented, "*…the people who come from a physics background are ultimately more pragmatic in computing. […]if it requires you to wrap sellotape around it to get it to work, then they will wrap sellotape around it. The people who come from a computing background tend to […] have slightly purer model of how the computing should work...whereas the physicists are happier with an ad hoc solution just to get the job done and push them through.*"

5.3 Relational dimension

5.3.1 Sense of belonging

With members of the collaboration based in disparate institutes, it is important to develop an emotional bond among individuals for the project to function collectively. "*We have to work very well together as a team, in order for GridPP to be successful. And because as you will appreciate it's quite a complicated structure, there are multiple channels of communication, some of which are duplicated, some of which are contradictory, and there are all sorts of ways in which information flows. And anything that you can do to oil the cogs of the machine is going to help. And one of the things that are going on very well in GridPP is the cohesiveness of the deployment team. And I think for us to socialize together is a very important thing*". "Going to the pub" together when they meet, for example, is one aspect of it. "*It fosters a bond between people and helps.... it helps a lot I think because many aspects of working in this project are frustrating because it's so large. And so if you can go out together and you can identify the problems and let out steam about them, I think that's actually a very important social function of these meetings.*"

These emotional communications help to alleviate the anxiety they have to face, including the pressure of the LHC switch-on and that of showing the UK in a good light among the worldwide particle physics communities. The collaboration is committed, engaged, and is always "just about" on top of things. They seem to be constantly fire-fighting, discovering problems, managing crises, and negotiating solutions. Yet there is a high level of confidence despite the sense of urgency and disorder on the surface. Almost everybody in the collaboration that we interviewed holds a firm belief that the Grid will work; it may not work perfectly, but it will work.

5.3.2 Trust

Deriving from the shared tradition and shared goal is a high level of trust among people and institutions. One senior member of GridPP calls it *"a culture of trust and equality"*. The notion of trust also came out very clearly in our interviews: *"it's very important for the physicists because there's so many things that they have to do in order to be able to interpret something that's been true in the data, that they have to trust what other people have done. And this is even more so when you have such big detectors as the LHC ones."*

In GridPP, trust not only lies with people's intelligence and ability to deliver work, but more importantly, with people's commitment to their job and with readiness to make extra effort to ensure things get done. "*There will be problems coming out in all areas and you'll have to trust that people will step up to the plate and you know, do the dirty work as well as doing al the glamorous work you know, and things like that."* Trust seems to be what characterizes high energy physics as a community. "*So actually the trust between the different high energy physics computing centres is much larger than what, in most of our member countries, are the legal constraints."*

6 DISCUSSION AND CONCLUSION

How does the mobilization of social capital contribute to the social construction of knowledge (Blackler & Mcdonald 2000; Berger et al 1966) within GridPP? Table 2 illustrates the implications of social capital in facilitating innovation and knowledge socialisation. A flat structure of organizing combined with minimal direct management provides a positive environment for creativity, exploration, and experimentation such that individuals can socialise knowledge. This structure similarly allows peripheral participation by non-experts so they may learn and enter the community (Wenger 1998; Lave & Wenger 1991). However, to be productive, there needs to be guidance of a clearly articulated common goal; in this case to advance the science of physics. Such a shared vision can be viewed as a bonding mechanism that helps different parts of a network integrate knowledge (Tsai & Ghoshal 1998), and provides an important sense of identity for the group (Lave et al. 1991).

Although there are extensive communication channels in GridPP, limited effort has been put on structured codification of knowing as information (Nonaka & Takeuchi 1995; Nonaka 1994). While mailing lists, wikis and blogs provide potential for knowing, they are used in a highly unstructured manner and are not seen as an important collective resource of knowledge. What compensates the lack of a codification approach to knowledge (Hansen, Nohria & Tierney, 1999) is the emphasis on socialization and personalisation within GridPP (Hansen et al. 1999). Most of the members travel frequently to attend meetings, conferences and workshops, and make deliberate efforts to talk to people face-to-face. The construction of social connections within the project provides personal directory (Wegner 1987) to knowing - i.e. "who knows what". This process of socialization must however be sustained through the relational dimension of social capital, as illustrated by the ongoing

Table 2 Social capital and knowledge processes

Social Capital		Processes of knowing
Structural dimension	Network structure	Enables free flow of knowledge Avoids too many layers of decision making and bureaucracies Allows knowing to emerge in a bottom-up manner, and circulate in the "ecosystem"
	Decentralized management	High level of individual freedom provides incentives for sharing expertise and acquiring knowledge. Encourages creativity and improvisation Lack of centralized knowledge depository may lead to loss of knowledge
	Extensive communication channels	Encourages knowledge creation, especially across organizational and geographical boundaries
Cognitive dimension	Shared goals	Motivates knowledge acquisition of individuals Provides incentives for social construction of knowledge Fosters individual commitment and devotion Encourages co-operation
	Shared culture	Provides shared understanding Facilitates communication Lower barriers from the tacit dimension of knowing (Polanyi 1967).
	Norms (of pragmatism)	Provides a "safety-net" which tolerates mistakes while encouraging creativity and problem solving
Relational dimension	Sense of belonging	Socialization facilitates sharing of tacit knowledge Supports collaboration and knowledge integration
	Trust	Promotes willingness to share knowledge

maintenance of trust and a sense of belonging. As the development stage of the grid draws to and end, and emphasis is shifted to maintenance and improving reliability of the Grid, such mobilization of social capital through formal and informal forms of interpersonal communication is gradually being balanced, but never replaced, with a systematic and impersonal arrangement of communication and technical support.

To conclude, the paper has drawn upon the concept of social capital to examine challenges faced in distributed systems development. The analysis on the empirical study of a complex project of system development allows us to reflect and explore dimensions of motivating, organizing, and coordinating distributed members of a systems development project and their implications for processes of collective knowing. Our findings are aligned with existing perception of social capital in the literature. Social capital has been found to enhance division of labour by reducing costs of coordination, induce and speed up sharing of tacit knowledge, and encourage co-operations, which in turn fosters firms' innovative capability, competitiveness and ultimately economic performance (Maskell, 2000). In an era where distributed projects have become increasingly prevalent, our case generates implications for the importance of mobilizing social capital in distributed systems development processes, especially in terms of providing shared goals and culture, supporting individual creativity and building trusts in the community.

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