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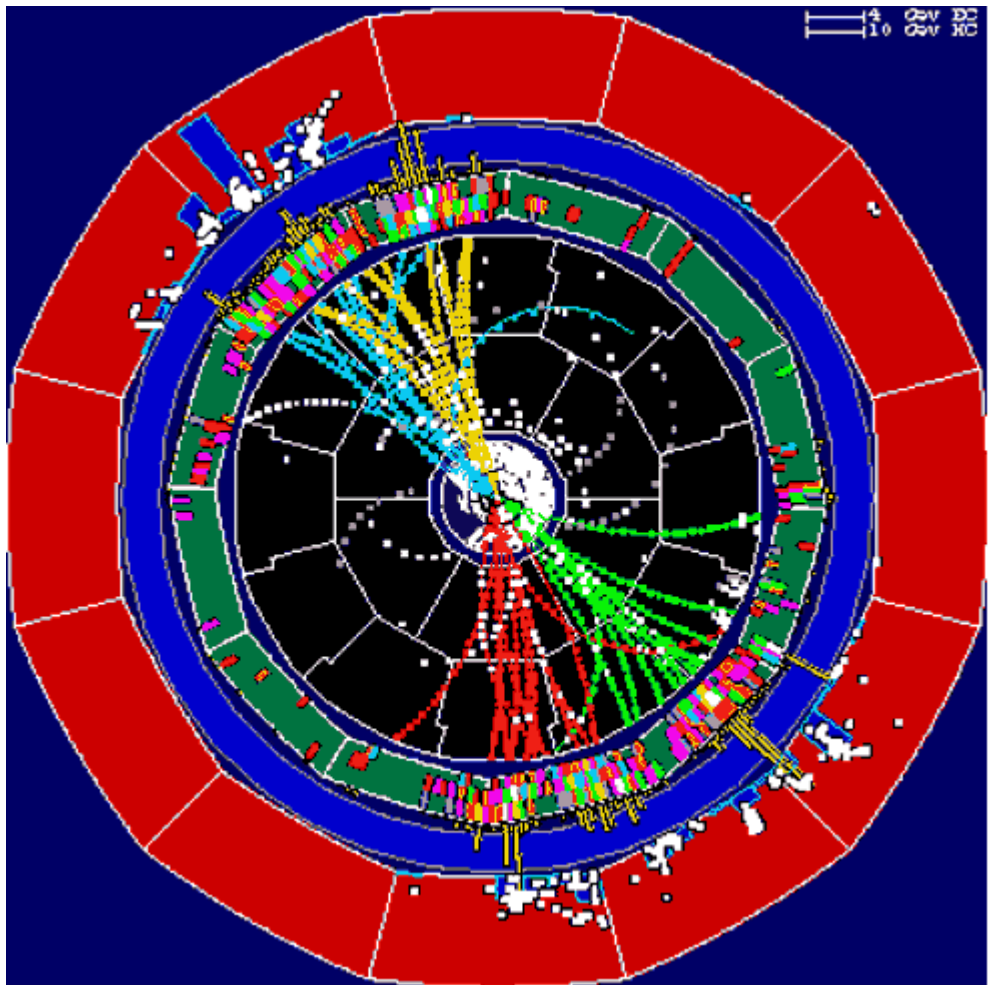
**How is the Particle Physics
Community shaping the Grid in the
UK?**

1st September 2004

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'Any sufficiently advanced technology is indistinguishable from magic.'

-Arthur C. Clarke



(Source: http://www.space.com/business/technology/technology/grid_000928.html)

'A computer reconstructed image of an event at the particle accelerator in CERN, Geneva, where electrons and their antiparticles are smashed into one another.'

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Abstract

Far from being a straightforward, the development of an information infrastructure is a complex socio-technical task. This paper focuses on identifying some of the issues and challenges in developing the Grid within the particle physics community in the UK. By drawing on a minimalist version of actor network theory, we explore how the respective interests of both technical and non-technical actors are inscribed into a newly forming actor network. By assessing the extent to which these inscriptions have been aligned and subsequently linked, we assess the relative 'state' and therefore stability within the network. Some insights are made regarding standards, the user community, the adoption of the Grid and the building up of an installed base.

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TABLE OF INTERVIEWS

1. INTRODUCTION

In 2007, the Large Hadron Collider (LHC) based in CERN, the international research particle laboratory will be ‘switched on’. This is a large particle accelerator which will be running general purpose experiments used to answer some fundamental questions about the ‘nature of matter’. An unprecedented amount of data will be generated- estimated at several petabytes a year. In order to analyse and interpret the data, the UK particle physics community has committed to delivering the necessary information and communication technology infrastructure by 2007: the particle physics Grid. A Grid enables the sharing of resources and skills, core competencies or resources to better respond to large-scale computational and data problems in science, engineering and commerce (Foster & Kesselman 2004).

In the context of this paper, the particle physics Grid (referred as GridPP) is defined as an information infrastructure which incorporates distinct characteristics: that of an evolving, shared, open and heterogeneous installed base (Hanseth 2000, 2002). It follows that establishing an information infrastructure is far from being a straight forward task which at least includes raising funding for development, defining standards and ensuring they conform to bureaucratic procedures of standardisation bodies, customising and stabilising emerging technologies, and adapting these to various use scenarios (Hanseth 1997). By focusing on this complex socio-technical process we seek to understand some of the underlying factors that shape the development of an information infrastructure- before it has become a ‘black box’.

Actor network theory is used to explore the socio-technical interplay between the humans and non-humans by offering a language to describe how these elements influence, determine and shape the Grid (Monteiro 2000). The process of inscription (Akrich 1992, Akrich & Latour 1992) and translation (Callon 1994, Latour 1987), a minimalist version of actor network theory, allows the researcher to be more specific about how social and technical issues are interwoven into a developing information infrastructure (Hanseth, Monteiro, Hatling 1996).

The dissertation can be characterised by first underpinning a set of issues and relevant themes which develop a context for the empirical study of the particle physics community shaping the Grid in the UK. This highlights the socio-technical complexity of developing an emerging information infrastructure followed by some insights. It provides a unique and exciting opportunity to study the evolution of a newly forming information infrastructure.

1.1 Statement of Purpose

Our principle aim is to uncover some of the socio-technical realities of establishing an information infrastructure; in our case to understand some of the ways in which the particle physics community is shaping the Grid in the UK? In particular, we wish to examine how a given actor within the network inscribes patterns of use and subsequently constrains others. Some of these inscriptions are non-technical whilst others are technical in nature, however both need to be considered to appreciate the complex process of developing an information infrastructure (Monteiro 2000). Attention is given to aligning and linking inscriptions in an effort to glean their relative strength and establish the degree of irreversibility within the actor network (Hanseth 1997). Some insights are gained regarding the difficulty in agreeing standards, the subsequent interoperability issues experienced, the impact this has on the user-community, with some attention given to the installed base of technologies, users, experience that will ultimately shape the Grid as it evolves.

1.2 Structure

This paper is organised into the following sections: a short introduction is given followed by a statement of purpose and an outline of the research methodology used for this thesis. In section 2 a brief literature review of the Grid is provided with particular attention being given to the issues encountered by the Grid community. Section 3 introduces the Grid as an information infrastructure and highlights the importance of standards and an installed base. In section 4 we introduce the actor network theory and in particular the concept of an inscription and translation based on the understanding that this gives us a deeper insight into the relationship between information technology and its use. Section 5 provides the case study narrative: the need for the particle physics Grid is discussed from the perspective of some of the actors within this complex actor network. In section 6, the analysis based on actor-network theory is presented. This is followed by a discussion in section 7 where some lessons regarding a developing information infrastructure are highlighted. Section 8 concludes the paper. In section 9 limitations of the research are outlined with suggestions for further research.

1.3 Research Methodology

Information systems (IS) are social systems, made up of a set of technical, scientific and human resources devoted to managing information. Their behaviour is 'heavily influenced by goals, values and beliefs of individuals and groups, as well as the performance of the technology' (Angell & Smithson 1991). This highlights the composite nature of information systems which makes conducting research in the IS field complex. Therefore to adopt a positivist approach to IS research of measurement, formalisation and calculation neglects the very essence of information systems. As posited by Ciborra (1998) human existence represents the essential ingredient of what information is, and of how reality is encountered, defined and described.

What is needed is a methodology which can produce 'an understanding of the context of the information system, and the process whereby the information system influences and is influenced by the context' (Walsham 1993). This puts an emphasis on human interpretation and understanding where the researcher is not regarded as a neutral observer. Such an interpretist approach is increasingly favoured by the researchers in the field (Hirschheim 1985, Walsham 1993, 1995). For the purposes of this paper, it allows us to consider the distinctive qualities of the Grid as an information infrastructure; a socio-technical network with interrelations and interdependencies between the various human and non-human actors.

Qualitative methods allow the study of a phenomenon from the point of view of the participants and its particular social and institutional context. According to Miles & Huberman (1994) qualitative research is based on words rather than numbers. It follows that a qualitative, interpretist approach is the most useful in uncovering how various actors interplay in shaping the Grid within the particle physics community. The outcome of this research is to provide a 'snapshot' into the dynamics and negotiation of actor relationships and the subsequent attempts that determine the way in which the information infrastructure is being developed.

For this purpose a series (5) of semi-structured interviews were conducted and summarised into a case study (description)-this is useful where there has been limited prior research on the Grid from a social science perspective. Semi-structured interviews are beneficial in that they allow the researcher to develop a 'natural' relationship with the interviewee which encourages a purposeful conversation; the case study is then used to shed light on the topic by providing an in-depth narrative (Cornford

&Smithson 1996). Conversely, it can be argued that case studies provide only limited information which may therefore not be representative of the whole particle physics community. Moreover, this approach allows for an element of bias introduced by the researcher. It follows that it was a challenge to convey all of the subtleties expressed by the interviewees within the limited scope of the dissertation.

The following section introduces the concept of the Grid by drawing on related literature and highlights the issues faced by the Grid community.

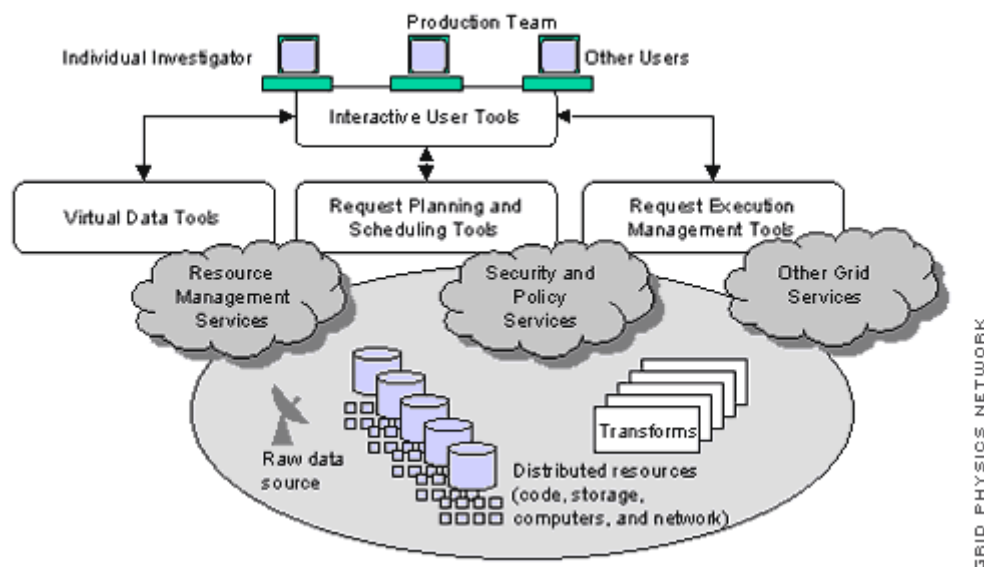
2. THE GRID IN CONTEXT: RELATED TEXT

The development and deployment of Grids across the globe is at its early stages. Therefore a large part of Grid literature is centred on reviewing and advancing technical and architectural aspects of the Grid. This is especially significant at a time when underlying Grid standards and technologies are being defined and agreed. Some papers provide a generic overview of Grid computing and its technologies (and projects) (Baker et al 2002, Goble & Roure 2002, Johnson et al 2000, Grimshaw & Wulf 1997, Rajsbaum 2002, Chetty & Buyya 2002, Walker 1992), whilst others focus on addressing a specific Grid component (Coddington 2003, Malaika et al 2003, Snavely et al 2003, Nagarajan et al 2001, Wolski 2003).

This paper can not be categorised into any of the above areas. Its main contribution is the insight it provides into the complex socio-technical process of establishing an information infrastructure.

The following introduces the concept of the Grid and outlines some of the reasons why the Grid is an emerging information infrastructure:

The availability of powerful computers and high speed network technologies at low cost coupled with the widespread use of the Internet has enabled the possibility of using distributed computers as a unified computing resource (Baker et al 2002, Perrott 2002). Grids therefore enable the 'selection, sharing and aggregation of a wide variety of resources' including people, supercomputers, storage systems, data sources and devices that are geographically dispersed and owned by different organisations (Baker et al 2002, Goble & De Roure 2002, Perrott 2002). Foster et al (2001) defines the Grid as 'a flexible, secure, coordinated resource sharing among dynamic collections of individuals, institutions, and resources-what we refer to as virtual organisations'. Virtual organisations are created to share resources and skills, core competencies or resources to better respond to large-scale computational and data intensive problems in science, engineering and commerce (Foster & Kesselman 2004, Baker et al 2002, Goble & De Roure 2002). For a discussion on how Grid computing differs to similar models such as distributed computing, business-to-business exchanges, peer-to-peer computing, and utility computing see Foster al 2001, Foster et al 2002 & IT Professional 2004.



(Source: http://www.space.com/businessstechnology/technology/grid_000928.html)

The above diagram shows a production Grid. This demonstrates 'the integration of data generation facilities, storage, computing and networks, plus tools for scheduling, management and security'.

The Grid, as a term, was initially coined based on an analogy between the electricity power Grid (see Chetty & Buyya 2002) in allowing seamless, dynamic and transparent delivery of computing and data resources when needed. Smarr (2004) refers to the Grid as an 'emerging infrastructure' that will satisfy society's computing needs in the same 'pervasive and ubiquitous manner' as the electricity power Grid. He argues that the Grid will have serious social consequences; just as the railroads did in the American mid-West in the early 19th century. However, unlike the railroads, Grids 'are going to change the world so quickly that we are not going to have much of a chance-on a human, political, or social time scale-to react and change our institutions' (Smarr 2004).

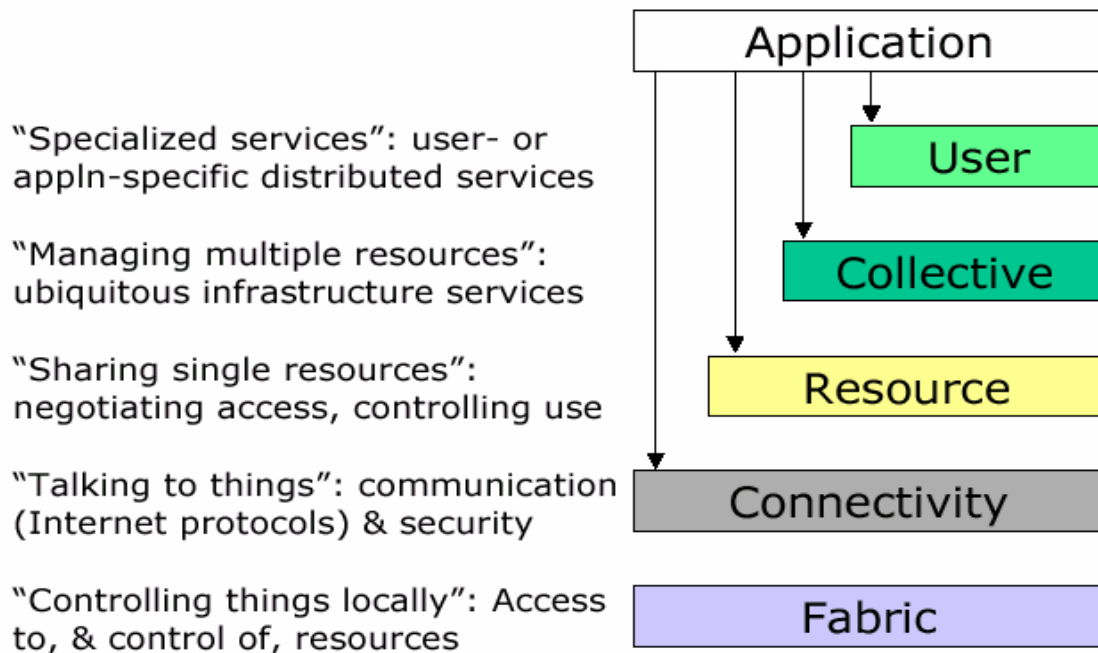
Initially, the Grid was focused on sharing computational power and resource for science and engineering only. In the 1990s 'metacomputing' projects were set up to build virtual super computers using networked computer systems (Goble & De Roure 2002) however the scope of the Grid has gone beyond that: the Grid infrastructure can benefit many applications from collaborative engineering, to commerce (Baker et al 2002). For example, Ellisman & Peltier (2004) discuss the Grid for medical research and patient care, whilst Stevens (2004) explains how the Access Grid can support group-to-group human interaction across the Grid. Levine & Wirt (2004) highlight the use Grid for gaming (for the Butterfly Grid), whilst the Deutsche Bank Grid report (2000) discusses what Grid computing means for commerce and how industry can benefit from these developments.

The concept of the Grid has taken many forms within different projects however the general view to date is that it should be made up of a number of service components (Perrott 2002). These are computational services, data services, application services, information services and knowledge services (see Baker et al 2002).

From the perspective of the particle physics community, data services are needed for the management, sharing and processing of large data-sets. These data sets may be replicated, catalogued and even stored in different locations. The processing of datasets is carried out using computational Grid services and are commonly known as data Grids (Baker et al 2002, Perrott 2002, Foster & Kesselman 2004, Newman et al 2003). The LHC Grid, which is in part being developed by the particle physics community in the UK, is an example of a data Grid.

To enable the seamless availability of resources through the virtual organisation, the Grid must interoperate with a whole spectrum of current and emerging hardware and software technologies (Baker et al 2002, Foster et al 2001). Interoperability is therefore a central concept in Grid computing.

The following diagram summarises the different layers that make up the Grid and illustrates the need for interoperability:



(Source: Foster et al 2001).

As the Grid is heterogeneous in nature, has multiple administrative domains and autonomy, will need to be scalable as well as dynamic in terms of its use of resources and services (Baker et al 2002), an open-based architecture is needed: standard protocols supported by Application Programming Interfaces (APIs) and Software Development Kits (SDKs) (Foster et al 2001). Together, this technology and architecture, known as middleware, can turn a heterogeneous environment into a homogeneous one (Baker et al 2002).

It follows that using standard, open, general-purpose protocols and interfaces are critical for the development of Grid computing (Foster 2002, Foster & Kesselman 2004, and Perrott 2002). Grid technologies provide mechanisms for sharing and coordinating the use of diverse and geographically disparate resources to deliver desired qualities of service (Foster & Kesselman 2004). These might include security solutions, resource management protocols and services, and information query protocols and services. The Global Grid Forum (GGF) is an industry and research group leading the global standardisation effort for Grid computing (Economist, 2004) which involves over 400 organisations in over 50 countries (Foster & Kesselman 2004). So far the community has developed the open-source Globus Toolkit version 2 (GT2) and the Open Grid Services Architecture (OGSA) into standards. Whilst the GT2 focuses on usability, interoperability, protocols, APIs and services (Foster et al 2002, Foster & Kesselman 2004) OGSA represents a natural evolution from GT2 and aligns Grid computing with industry initiatives in a service oriented architecture and Web services (Foster et al 2002, Foster & Kesselman 2004, Economist 2004).

In spite of these developments, it is felt that that the Grid is 'where the Internet was in the 1990's' (Foster 2002). This is partly because standards are at a very stage of development; they are still being defined and agreed. Foster & Kesselman (2004) posit that 'much more remains to be done before the full Grid vision is realised'. This is also because competing and contradictory standards are being developed and used by the community making interoperability difficult. Schof & Nitzberg (2002)

illustrate this point by referring to two standards for information services: Globus Metacomputing Directory Service (MDS 2.1) and Grid Monitoring Architecture (GMA) each with individual interfaces, APIs and protocols in an overlapping space. Meanwhile large industry players seem to be building Grid applications which include their own proprietary software; this goes against the open source nature of OGSA (Economist 2004).

Therefore the development and deployment of Grid computing is faced with many challenges. In addition to the difficulties experienced with standards, Schopf & Nitzberg (2002) argue that there is a need to improve basic Grid functionality, create a ‘user community’, develop a security infrastructure, effectively manage the variance of resources on the Grid, ease the deployment of software with appropriate software tools, with a need for performance metrics. Moreover, Medeiros et al (2003) explain that Grids, because of their heterogeneous nature, are more prone to failures than traditional computing platforms. This implies issues relating to scalability and dependability (Goble & Roure 2002, Grimshaw & Wulf 1997, Schlichting 2002) whilst highlighting problems for users in terms of needing to often diagnose and address ‘faults’. It follows that users require a level of technical expertise coupled with a ‘heroic’ attitude. This time and effort is regarded by some as a distraction from getting the ‘real science done’ (Schopf & Nitzberg 2002). However the challenges posed by the Grid are not only technical: Schopf & Nitzberg (2002) refer to a number of socio-political issues including communication between different groups developing the Grid, adding incentives for sites to be part of a user-centric/ ‘fair play’ environment and resource usage policies. Various large-scale Grid projects highlight some of these difficulties but are also able to demonstrate progress creating services, architectures and design principles in deploying Grid testbeds. For example, the NASA Information Power Grid (IPG), (Johnson et al 2002), the Legion project (Grimshaw & Wulf 1997), the European DataGrid (Walker 1992).

This paper is centred on GridPP. The following section explains how the Grid is an emerging information infrastructure.

3. THE GRID AS AN INFORMATION INFRASTRUCTURE

An infrastructure can be characterised as a close interplay between the heterogeneous character of systems and institutions based on the concept of 'flow' (Edwards 2003). An information infrastructure is considered an elusive term and is often compared to an info-bahn or the electronic highway (Hanseth, Monteiro, Hatling 1996). Star, Bowker and Ruhleder, through a series of studies, develop the perspective of an infrastructure technology as being far more complex than that of an 'artefact'. Star & Ruhleder (1994) typify an information infrastructure as 'fundamentally and always in relation'. Hanseth (2002) differentiates between three types of infrastructures: the global 'universal' service infrastructure (such as the Internet), the EDI and business sector infrastructures (interorganisational) and corporate infrastructures (organisational). It follows that the Grid can be categorised as an emerging 'global universal service infrastructure' in that it will ultimately become a foundation upon which many activities and services will be based.

Webster's dictionary defines infrastructure as: 'a substructure or underlying foundation especially the basic installations and facilities on which the continuance and growth of a community, state etc depend such as roads, schools, power plants, transportations and communication systems.' (Guralnik 1970, quoted in Ciborra & Associates 2000 pg 56)

According to Hanseth (2000, 2002) information infrastructures incorporate a number of distinct characteristics- this contrasts to the definition of an infrastructure in management literature which regards information infrastructures as largely 'unproblematic' (Ciborra & Associates 2000).

An information infrastructure has a supporting or enabling function; it is shared by a large community and can not be split into separate parts (Hanseth, 2000, 2002, Ciborra 2000). Moreover, an infrastructure continuously evolves which implies that it is also 'open': there is no limit to the number of elements it may include. For example, the number of users, nodes in the network, application areas and so on is not limited. Therefore information infrastructures do not have 'borders': they do not have a 'beginning' or an 'end' (Star & Ruhleder 1994, Ciborra 2000, Hanseth 2000, 2002).

Hanseth (2000, 2002) further argues that infrastructures are heterogeneous in nature; they are made up of technical and non-technical components. Moreover, as larger components are built on existing smaller, independent components, a change in one of these components changes the other elements in the 'network'. This implies a constant need to adapt to new requirements. Therefore the new version of the infrastructure must be 'backward compatible' with the existing components. (This raises the 'issue' of needing to standardise an information infrastructure whilst maintaining a level of flexibility; see Hanseth, Monteiro, Hatling 1996). The design and development of an infrastructure is therefore influenced by the existing components; otherwise known as the installed base. This makes the installed base a powerful actor in the network as 'it plays a crucial role as a mediator and coordinator between the independent, non-technological actors and development activities' (Ciborra 2002). This is also because as the installed base grows non-technical actors align with the emerging information infrastructure, thereby strengthening the network. Therefore translating installed bases into allies is significant to creating new information infrastructures.

Moreover, the various components that make up an infrastructure are integrated through standardised interfaces. Standards are not only economically important, as bilateral arrangements between parties are too expensive and difficult to manage (Hanseth, Monteiro & Hatling, 1996, Shapiro & Varian 1999), but they are critical to enabling an infrastructure. Moreover, Ciborra (2002) posits that standards, far from being mere technical artefacts, 'should be viewed as complex, heterogeneous actor

networks' made up of a critical mass of users of technology and infrastructure. A standard which can establish a critical mass of users ahead of others is likely to be cumulatively more attractive (Shapiro & Varian 1999). Also, small benefits demonstrated in the early stages influence the development of the standard through network externalities and positive feedback-often leading to lock-in and irreversibility (Hanseth 2000, Shapiro & Varian 1999).

Moreover, Ciborra and Lanzara (1994) introduce the notion of information infrastructures as formative contexts: 'sets of pre-existing institutional arrangements, cognitive frames and imageries that actors bring to, and routinely enact in a situation of action'. It follows that social and political elements, as well as history and context condition action, meaning and direction of how an information infrastructure, and therefore, standards develop.

It follows that the Grid is an information infrastructure is an installed base which evolving, open, and heterogeneous. The next section of the paper introduces the actor network theory which will be used to analyse the case study.

4. ACTOR NETWORK THEORY: INSCRIPTIONS AND TRANSLATIONS

4.1 What's so special about the Actor Network Theory?

The interplay between technology and society has been addressed from a number of perspectives. The extreme perspectives are that of technological determinism (Winner 1977) and social reductionism or constructionism (Winner 1977, Pfaffenberger 1988). Technological determinism is based on the premise that the development of technology follows its own logic and determines its use, whilst social reductionism or constructionism holds that society and users develop the technology they want, use it as they want and subsequently, that technology has limited if any level of influence (Monteiro 2000).

The view held by the majority of the scholars in the field is between these two extremes; an intermediate position of information technology having both 'restricting and enabling implications' (Orlikowski & Robey 1991). This is supported by a variety of theoretical frameworks including structuration theory (Orlikowski & Robey 1991, Orlikowski 1992), and hermeneutics (Klein & Myers, 1992).

Actor network theory can offer a deeper insight into the relationships between information technology and its use (Akrich 1992, Akrich & Latour 1992, Callon 1994, Hanseth 1997, Hanseth et al 1996, Monteiro 2000, Ciborra 2002). This is based on the understanding that ANT offers a language which enables a the description of social and technical mechanisms and the way in which they influence, determine and shape the development of a new information infrastructure-such as the particle physics Grid.

Actor network theory views society as a socio-technical and heterogeneous network. It is made up of interacting human/non-human actors and social elements all viewed with equal status and importance (Akrich & Latour 1992). As posited by Law (1992), 'this is an analytical stance, not an ethical position'. More specifically, social and technical elements of a socio-technical network are not distinguished in the first instance, allowing for a detailed description of the concrete mechanisms that combine to glue the network together-without being distracted by the means (Ciborra & Associates 2000, Ciborra 2002, Hanseth 1997, Hanseth et al 1996). This allows for a level of detail and precision.

A minimalist version of the actor network theory will be used for the purposes of this paper: inscription (Akrich 1992, Akrich & Latour 1992) and translation (Callon 1994, Latour 1987).

4.2 Inscriptions and Translations

The notion of an inscription refers to the way a technical artefact embodies the patterns of use or how one's interest is translated into material form (Callon 1991). Positioned between the objectivist stance of technology determining use and a subjectivist stance of the artefact being interpreted and appropriated by the interaction of human agency, an inscription can describe future scenarios that enable and restrict the development and use of technology (Akrich 1992, Hanseth 1997, Monteiro 2000).

Inscriptions are made into various kinds of materials, such as artefacts, work procedures, written manuals, institutional and organisational arrangements; referred to as inscribing a 'pattern of use'

which by implication limits the flexibility of an information infrastructure (Monteiro 2000). Therefore uncovering the different materials for inscriptions, how and where patterns of use are inscribed, is relevant for the purposes of our discussion.

In order for an actor network to achieve stability and social order, actors' interests must be aligned through a process of negotiation. This is referred to as translation where interests are aligned by reinterpreting, representing or appropriating other actor interests to one's own. This generates the 'ordering effects such as devices, agents, institutions or organisations' (Law 1992). A translation presupposes a medium and can be 'embodied in texts, machines and bodily skills (which) become their support...' (Callon 1991). In this part of the process, the 'designer' works out a scenario for how the system will be used which is then inscribed into the system. By implication programmes of action are defined for the users and the technology; roles and competencies are delegated to components of the socio-technical network (Latour 1999). It follows that this programme of action will be imposed onto the users and technology. However, the user may deviate from the pattern of use or perhaps use the system in an unexpected way which is referred to as an 'anti-programme' (Latour 1991). In terms of studying a technical artefact, Akrich (1992) posits that it is necessary to shift back and forth 'between the designer's projected user and the real user' to explain the process of design. Similarly, this analysis can be extended to a non-technical actor.

Translations become durable when actors in a network are aligned, have gained momentum, and an actor network can resist competing translations. This implies irreversibility of an actor network based on the strength of inscriptions. Callon (1991) posits that the degree of irreversibility depends on a) the extent to which it is 'impossible to go back to where' the translation was competing amongst others, b) the extent to which it 'shapes subsequent translations'. It is never possible to know which inscription will achieve the given aim, but analysis of inscriptions opens the possibility to studying the sequence of attempted inscriptions which unravels the complexity of 'how and by which means inscriptions are achieved' (Ciborra 2002). According to Latour (1999), the degree of irreversibility may be regarded as a process of institutionalisation: the more a network is irreversible the more it has become institutionalised. Conversely, institutions can encourage the degree of irreversibility by aligning interests in the network.

Just as ANT refuses to distinguish *a priori* between humans and non-humans, it also refuses to distinguish *a priori* between small and big networks.

In this paper, the following aspects will be considered for the purposes of analysing and understanding how the particle physics community is shaping the Grid (Hanseth 1997, Monteiro 2000):

- The identification of explicit anticipations (or scenarios) for shaping the Grid
- How these anticipations are translated and inscribed into the materials of inscriptions.
- Who inscribes them
- The strength of these inscriptions-that is, the effort it takes to oppose or work around them.

The next section describes the case study: the particle physics community shaping the Grid.

5. CASE STUDY: THE UK PARTICLE PHYSICS GRID

5.1 Setting the Scene...

In 2007, the Large Hadron Collider (LHC) based in CERN, the international research particle laboratory will be 'switched on'. The LHC is an enormous particle accelerator which will be able to produce energies of 14 tera-electronvolts (14TeV).

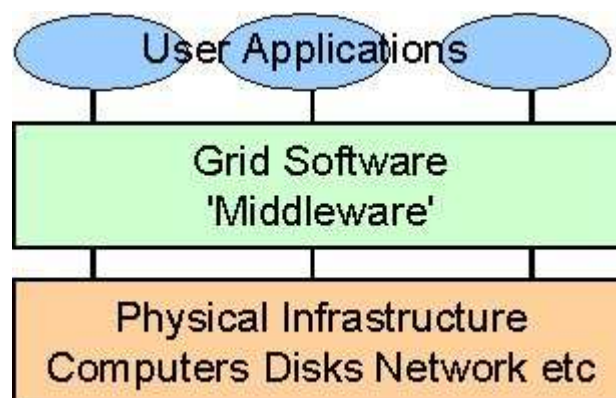
This will make it the most powerful accelerator in the world. General purpose experiments such as Atlas and CMS that will be carried out on the LHC will be the biggest experiments ever built and will allow particle physicists to investigate the very nature of matter. The LHC hopes to answer one of the biggest questions being asked by particle physicists today: what is mass? This will either be through the discovery and study of the Higgs Particle or through whatever other mechanism is responsible for breaking the symmetries involved in mass generation (LCG website; see ref.) where experiments will generate an unprecedented amount of data which has been estimated at *12-14* petabytes (one million gigabytes) of data each year, the equivalent of more than 20 million CDs: analysing this will require the equivalent of 70,000 of today's fastest PC processors! (LCG website; see ref.) This data will need to be analysed and statistical Monte Carlo simulated data generated in order to interpret the results.

There are two respective phases of the Grid development in the UK:

- GridPP 1: Grid prototype (1st September 2001 to 1st September 2004),
- GridPP 2: Grid production (1st September 2004 to September 2007).

There are three main developments within GridPP:

- Grid-enabled applications; and
- Grid software (*middleware*);
- Provision of computing infrastructure in the UK and CERN.



(Source: <http://www.gridpp.ac.uk/explain.html>)

5.2 Constructing the need for the Grid for the Particle Physics Community: GridPP

The UK Government carried out a Long Term Technology Review in 1997/8 which identified advanced IT as a requirement for science and technology. Increasing use of simulation, massive amounts of data and demand for CPU cycles and networking were highlighted as necessary areas for investment. From the perspective of the particle physics community which needed IT infrastructure for the LHC programme in 2007, the Grid seemed the ideal solution.

The UK E-Science programme was initiated in 2000-2001 by John Taylor. The Office of Science and Technology (OST) was given money to fund advanced IT to enable science. He then became Director General of Research Council at a time when the UK Treasury and various other people felt that that the UK was under-resourced in IT training. Most of the software for Physics came out of the US where there was more of an established tradition of applied IT. The UK government provided the Research Councils with funding for IT infrastructure.

5.3 Characteristics of Particle Physicists

The particle physics community has always been pushing the boundaries of computing:

'...the particle physics community is usually a few years ahead in terms of the amount of computing it is trying to use and the amount of data it is trying to manage...'

This is because the nature of particle physics research is based on analysing data-intensive experiment results as part of large international collaborations. Computing therefore plays a vital part in the community being able to carry out their pure science research. This necessitates software development and distributed computing capability and experience which the community has built up over the last twenty years. In fact, the particle physics community divides itself into those who focus on the pure science and those who choose to specialise in the computing side of particle physics. This implies a certain level of computing competency and self-sufficiency within the community.

Despite this, computing is regarded as being of secondary importance to the community. Particle physicists are not interested in learning about computing. Their interest lies in how technology can deliver to their scientific goals. Their pure science focus enables the particle physicists to take a rather more pragmatic approach to developing the necessary IT solutions (than the computer scientists):

'The computer scientists will put together the most elegant thing in the universe but it will never work...Physicists will come up with the most hacked solution in the world....but it will work...'

This 'no frills' and 'can do' approach has earned the community a reputation for 'getting things done'. As a community they are driven by what they want today and they are always very focused. The community is very good at making reliable solutions. This also has implications for helping the other scientific communities that have less experience. For this reason the particle physicists is useful to the Grid community.

The flip-side of the particle physicists' focus and pragmatic approach is that they will only do so much:

‘They won’t really solve the problem of the Grid...a sceptical computer scientist who works with biologists might say...it’s a waste of time giving the money to particle physicists because they’ll solve their own problem and they won’t solve the problem for the biologists...’

5.4 We need the Grid...money, money, money...

Based on their Peer Review and Strategy committee meetings, the Particle Physics and Astronomy Research Council (PParc) were aware that they needed additional funding for computing. In order to analyse data for the LHC programme, the community would have to upgrade their computer resources. As the majority of their budget had been allocated to building detectors, they were actively looking for opportunities to support this effort.

As part of the E-Science programme, funding for ‘advancing IT’ became available. This funding was based on a collaboration effort with computer scientists with various pseudo-rules associated with it. Research Councils had to account for their spending on a quarterly basis.

In 2000, PParc raised a call of opportunity specifying the availability of E-Science funding. This funding was ‘ring fenced’ for investment in advanced IT and computer scientists. By implication, accessing this funding would mean delivering an E-Science programme. Deploying the Grid would allow the community to do that whilst allowing for the necessary computer resource upgrade for the LHC programme. Moreover, aligning with the Grid meant that PParc could eventually move all their computing into the Grid environment and eventually support their existing experiments.

The UK particle physics community came together and proposed the GridPP as a collaboration and project. (In April 2004, a GridPP Press Officer was appointed to improve communication about Grid developments between the community.) They proposed the deployment of the Grid in support of the LHC programme in 2007. What was significant was that the community proposed that they could deploy gradually developing Grid technologies to support existing experiments not just as the development towards the LHC programme. Moreover, the community drew on their extensive track record in generating and analysing large amounts of data. This and the fact that the community ‘invented’ the World Wide Web built up a strong case for the particle physicists to become beneficiaries of the available funding:

‘...a lot of this was predicated on the fact that we had invented the Web...if we invented the Web, then we could invent the Grid...’

5.5 Healthy Scepticism....

Some members of the community regard the Grid as a ‘fascade’ used to generate funding for the computer resources required for the LHC programme. The particle physics community believe that they could meet the LHC challenge without the support of the Grid:

‘...I actually think that particle physicists regardless of a Grid or not can analyse the data and people are smart enough to do it...’

This may partly be explained by the fact that all the available funding has gone to advancing IT. No additional funding was made available for particle physics which has subsequently created some tension within the community. It follows that there has been limited acceptance of the Grid by the community to date. Justifying the time spent on developing the Grid technologies can be seen as difficult and in conflict with what the community needs to do:

'...everyone has to contribute to developing this and debugging it and using it...while you're doing that, you could be doing something else basically... I can get data myself and do it and it's all right and I can do it quicker than using the Grid...'

5.6 Growing Pains...

The process for initially being set up for the Grid has been somewhat slow: for one institution it has taken almost a year since the initial purchase order was sent out (requesting computer resources):

'...it's taken almost a year to get to the stage whereby you've decided on the operating system, you've decided who's going to manage it, you've decided on the analysis, how you submit your jobs to this thing and who's allowed to do what otherwise it's just anarchy...'

It follows that at these initial stages, the use of the Grid involves a large human element making the use of the Grid anything by 'seamless'. Moreover, the heterogeneity of software and hardware components between sites implies a need for standard interfaces. Although at some local level this has been made possible, standard interfaces are yet to be developed to allow for general Grid interoperability:

'And it's always on the interfaces that I can just about control my 20 computers along here and I can just about, by going for about 20 different management meetings, get onto 200 PCs in 'X' but getting onto 20,000 PCs across Europe...it's still not actually happening'

Grid technologies are immature and subsequently unstable. Users therefore can spend a substantial amount of time debugging and customising (software); they have to learn more about the technology than perhaps is relevant. Therefore, often users are expected to have a certain level of technical expertise to address immediate interoperability issues:

By implication, users need to have a 'gung-ho' attitude in order to start using the Grid with a view that it will take anywhere between one week to two weeks to understand how 'it works'. It is not surprising that users do not have to use or are not expected to use the Grid. There are currently no policies in place which specify using the Grid, although this is likely to be introduced once the Grid becomes more stable and scalable.

At the moment there are a small number of prototypes working in 'silos' in the UK. In time these will have to interoperate and scale sufficiently to allow for a few hundred jobs to be submitted without the Grid 'falling over'.

5.7 Battle of the Standards

Some standards upon which to build Grid services are yet to be defined between W3C, Oasis, DMTF and the GGF (see glossary). However, agreeing on standards is proving to be difficult.

IBM in collaboration with Globus defined the Open Grid Services Infrastructure (OGSF). After several years of development within this closed collaboration, OGSF was presented to the community as the new standard only to be withdrawn on the grounds that the Systems Group of IBM did not agree with it. This led to IBM redefining the OGSF to the Web Services Resource Framework (WSRF), a modular version of OGSF, but in so doing, alienated key players such as Oracle. The Enterprise Grid Alliance (EGA) was set up as a way to counter what Oracle regarded as being an attempt by IBM to monopolise the direction of the standards.

In the meantime, the collaboration between IBM and Microsoft set up to define the new web specifications for Grid services is yet to result in a public release of standards without which it is difficult for the community to build higher level services. This in turn limits the development of Grid services.

'It is a huge embarrassment to IBM that we haven't done this...and Microsoft...because overall we are inhibiting the development of IT...'

The particle physics community is also having to make some choices of their own in adopting existing standards in order to deliver a programme of science; standards which may or may not change in the near future. It is in the community's interest to influence the IT industry to develop and come on board with the standards they are trying to develop.

5.8 One Step at a Time....

Data challenges are being run on an annual basis whereby fake data is generated to test the Grid infrastructure. The idea is to be able to identify a specific X particle/X event which is hidden amongst the masses of generated data. If this can be done as part of the data challenge, then by implication this should be possible with real data.

Meanwhile the LCG tool release is an example of the progress being made by the community. Six months ago, the first tool release was unstable and difficult to install. Therefore LCG1 had not been installed in many sites. With the release of LCG2, the installation is much easier which has enabled over 300 worker nodes to be connected accessing substantial CPU.

5.9 To be first...

Being one of the first science communities to be involved in developing the Grid in the UK, the particle physics community is likely to have a strong influence:

'Particle physics is in a good position because it can essentially dictate to all sciences what software they should install on the Grid....this is going to spread out from particle physics...'

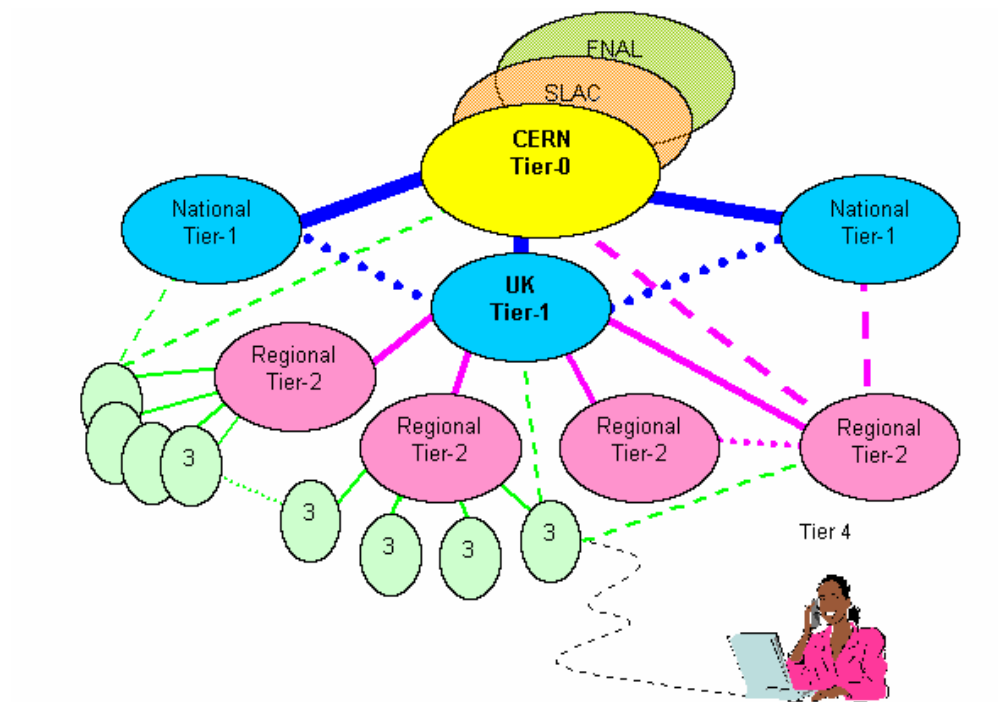
Moreover, Grid technology will be deployed over the UK in support of computer chemists and computational scientists. Already at this stage, it is being anticipated that the software needed for this will be the software developed and deployed by the particle physics community:

'...and I'm backing the particle physics community to come up with software that I need to make it work....'

5.10 The GridPP Hierarchy

The Grid in the particle physics community is based on a hierarchical structure-which also largely supports the community's collaborative nature. All data will be generated at CERN where the four LHC experiments will be running. The raw data will be stored at CERN with sub-sets being stored in Tier 1 centres; large traditional computer centres in the large collaboration countries such as US and the UK. A further subset of data will be available at the Tier 2 centres. These are virtual centres made up of groupings of institutes-ScotGrid, North Grid, South Grid and London.

The following diagram illustrates the hierarchical structure of GridPP:



(Source: http://www.gridpp.ac.uk/ab/doc/GridPP_Proposal.doc)

This top-down approach is based on a resource-limited and resource-efficient view of managing computing resources and of managing data; an end user does not need constant access to 50m CDs of raw data. This also feeds into the socio-political realities of how the computing for LHC is resourced at CERN; no individual country will singularly fund all the computer resources at CERN.

6. ANALYSIS

We now focus specifically on how various actors within the defined socio-network inscribe their interests and how these interests are translated in an effort to align others to their actor network. These actors include the Grid, the particle physics community, GridPP, PParc, E-Science programme. We consider the strength of inscriptions and reflect upon the stability of the network.

6.1 Creating the Actor Network...

The UK government's Long Term Technology Review (1997/8) identified advanced IT as a requirement for science and technology. By 2000 the UK E-Science programme funding became available for advancing IT in the research community and PParc had recognised that funding was required to enable the particle physics community to support the LHC programme in 2007. In order to meet their respective interests, the actors had to align themselves into a newly forming network. Their varied interests would become aligned into building an information infrastructure-that of 'constructing the Grid'. Therefore the UK E-Science programme and PParc aligned their interest for mutual benefit. From PParc's perspective, alignment with the E-Science programme would also ensure a steady source of funding.

To secure this funding, the particle physics community had to be aligned to the newly forming network. PParc inscribed its (programme of action) interest by initially 'ring fencing' the E-Science investment by specifying how the funding should be used, thereby becoming an 'obligatory passage point' (Latour 1987) to access the funding:

'It was a very useful tool for the senior management of collaborations to be able to say: we can't have anyone for computing unless we do that...And that convinces people to do it that way at some level....'

By aligning with the Grid as an ally in the actor network, PParc enrolled the support of the particle physics community on the basis of needing to achieve a scientific goal; that of the LHC programme in 2007. The LHC programme provided a 'flag in the sand' which was an effective way of focusing and aligning community effort to the actor network.

The particle physics community aligned with PParc and in turn with the Grid as a way to support their interest of achieving their scientific goal in 2007. This was translated into forming the GridPP collaboration which became the Grid project functioning body for the Grid development and deployment in the UK. New corporate structures and reporting mechanisms were put in place to ensure effective management of the project. GridPP appointed a Press officer in April 2004 in order to inscribe messages related to Grid development progress in order to strengthen the alignment with the particle physics community in the respective institutes. Messages pertaining to the efficiency and ease of use have been translated into a website, posters, conferences and relevant seminars.

The community as a whole was able to align with the Grid and inscribe their interests into the LHC programme as a way of enrolling the E-Science funding. Already identified as a science priority by the UK government, LHC represented a high profile project with a deadline:

'...there is this big flag in the sand where in a few years time it has to work...'

The E-Science programme translated their interests into giving PParc a ‘lion share’ of the funding available and aligned with the particle physicists’ experience, pragmatic and focus driven approach to deliver the Grid E-Science programme by 2007.

6.2 The Particle Physicists

As a community, the particle physicists inscribe their pragmatic approach and experience in computing into developing the Grid. As they are driven by the LCH programme deadline of 2007 and consider technology of secondary importance, they translate their programme of action into ‘getting the job done’. It follows that they will only do what is required of them. This implies that the software may be ‘rough around the edges’ and difficult to use, but it will work. This is unlikely to solve the ‘overall problem of the Grid’. For example, there are security and ethical issues that will need to be addressed for the biologist community which the particle physics community will not resolve.

It follows that the community is inscribing their interests of needing to deliver an E-Science programme and translating this into their selection and subsequent adoption of standards and technologies. For example, new web specifications for Grid Services are yet to be defined by industry players, however the community is having to make a number of early decisions by opting for standards which may or may not change in the near future. Subsequently the particle physicists inscribe their interests of influencing the IT industry to develop and come on board with the standards they are trying to develop. At the same time, they community has to be flexible enough to adapt to newly defined industry standards as and when they emerge. As another example, the LCG software has had to be recently recompiled for CERN as a result of the UK running a different Linux version to the one required. The particle physics community are in a position where they can ‘dictate’ their choice of Grid software for the rest of the science community.

The collaborative and resource intensive nature of the community’s research inscribes a hierarchical structure on the particle physics Grid. These socio-political realities coupled with a need to manage data efficiently is translated into constructing a top-down data hierarchical structure where data is generated at CERN and sub-sets of that data is sent out to the remaining Tier centres.

It follows that the community is building up an ‘installed base’ including technologies, institutions, bodies, standards, experience, policies, and processes which will influence the future development of the Grid-especially within the scientific community. As this installed base will be built up before most other communities, it will become cumulatively path dependent especially; the installed base is highly influenced by small benefits demonstrated by the early stages (Shapiro & Varian, 1999, Ciborra 2002).

6.3 Visibility of the Grid.....Technical Actors in the Actor Network

Having reached a state where an actor network is aligned to the construction of Grid, we now consider some of the technical actors within the actor network as part of the ongoing development. The Grid is not yet a seamless and interoperable information infrastructure. This makes the technical actors in the actor network ‘visible’.

End-users are exposed to the heterogeneous nature of technical actors as standards are yet to be defined and agreed. Grid tools and technologies are at very early stages of development implying a raft of technical difficulties. These technical actors inscribe their patterns of use, which at the time of

writing, constrain behaviour for the end-user. Users who want to use the Grid are expected to have a certain level of competency, a certain amount of time and a great deal of patience!

A lack of standard interfaces between various operating systems such as Windows XP and Linux, for example, inscribes a need for users to have a level of technical expertise to allow for interoperability. This pattern of use may be witnessed when users are involved in customising software sometimes on a per analysis or per experiment basis. It follows that users who do not have this level of expertise nor a 'gung-ho' attitude will currently find it difficult to use the Grid. Moreover, the immaturity and instability of Grid tools and technology inscribes a considerable amount of time and effort on the part of the end-users. For example, the resource broker (see glossary) on a given site used to crash once a day often meaning that the jobs that had been submitted to it earlier in the day had not been completed. This inscribed the need for end-users to manually check procedures and processes and fix any problems.

6.4 The Strength of Inscriptions....to Irreversibility...

According to ANT, inscriptions have to be linked to large actor networks in order to give them sufficient strength: this is based on 'trial and error'. A program of action is inscribed into a growing actor network until the necessary strength is achieved. (Hanseth 1997)

PParc aligned its interests with the E-Science programme which translated into forming a stable network of constructing the Grid. By accepting the significant funding that was provided to support the advancement of IT within the research community, the actor network became durable, and therefore irreversible. The network was further strengthened by PParc's interests translating into setting up GridPP; a formal governing body for managing and developing the Grid for the particle physics community. By the particle physics community aligning with these interests, the network gained more strength and subsequent momentum (Callon 1991).

Based on the large investment and the fact that the LHC programme is considered a high profile science priority, the actor network became stable-the Grid will be deployed for the LHC programme in 2007.

The converse is true in the setting up of standards. Actors do not seem to be aligned in their efforts to define and agree on standards:

'(there is).....existing chaos...real chaos for the Grid stuff. Sea of standards, duplicated standards, contradictory standards...this is a mess.'

This suggests a certain degree of 'reversibility' within the network; it is not made durable. Moreover, it is clear that attempts at an 'anti-programme' are possible as inscriptions are challenged by other 'power brokers', such as IBM and Oracle within the actor network and new interests are inscribed.

With respect to the technical actors in the actor network, inscriptions constraining use are not being made durable given the level of commitment to this project. Although there may be some delays by end-users who are balancing their normal workload with addressing Grid software bugs, progress is being made within the community. This suggests that the inscriptions of constraint are not being sufficiently translated into stability within the actor-network. Technical difficulties are being addressed as part of the prototype phase of the Grid roll-out, and the subsequent production phase. For example, the difficulties with the LCG1 release were addressed in the LCG2 release.

However, at this stage of the Grid development there seems to be a level of scepticism amongst individual particle physics communities. Doubts over whether there is a genuine need for the Grid by the community seems to be a case in point. The particle physics community has demonstrated sufficient computing ability in the past, irrespective of the computing constraints, to suggest a 'real need' for the Grid. This has not been the case within the Life Sciences community where the 'real need' may be more acute based on their relative inexperience in computing. It follows that there is tension in the particle physics community in the time and effort required for development of the Grid and pure science research. As the community is at the 'cutting edge' of developing the Grid technologies and tools they are often exposed to issues of software immaturity, instability and unreliability. This makes acceptance and subsequent adoption of the Grid difficult. As considerable motivation and 'gung-ho' is needed to use the Grid, the user community is relatively small.

These sentiments suggest a level of 'instability' within the network. In spite of the particle physics community as a whole being aligned to the actor network, there appear to be smaller actor networks with individual interests that are not aligned. This is important as these individual groups of particle physicists represent the end-user community. Although it is possible to speculate that by 2007 the technical difficulties would have been ironed out sufficiently to enable to adoption of the Grid, it remains to be seen to what extent this shall be possible-even with governing bodies in place to guide the process.

7. DISCUSSION

The particle physics community play an important role in developing the Grid. This is largely based on 'being first' among the science communities to influence both the Grid technologies/tools and standards. The small decisions taken at this early stage are likely to have a significant influence on how the Grid develops as this builds up an installed base including technologies, standards, experience and end-users. If the installed base becomes cumulatively attractive, subsequent Grid development for the science community may become path-dependent (Shapiro & Varian 1999, Ciborra 2002). Already at this stage, we are witnessing the particle physics community choosing particular technologies and developing them based on their requirements. Further Grid developments within the science community are likely to be based on this installed base. The characteristics of the particle physics community within the set context of working to a tight deadline also contributes to this 'installed base'

The Grid is not yet an information infrastructure in that its heterogeneous components are visible and the necessary standards are not yet defined to enable interoperability. This exposes the particle physics community to the 'growing pains' of developing Grid technologies and standards that are at their very early stages. By implication, the development of an information infrastructure is far from being straight forward. There are many socio-technical issues that underpin its evolution. It follows that despite the initial interests of the need to construct a Grid being aligned; subsequent interests of how and when this happens are not. For example, IBM and Microsoft are delaying the development of new web specifications for Grid Services which the particle physics need to deliver their E-Science programme by 2007. The agreement and adoption of a standard will not take place unless the actors in the network are aligned (Hanseth 1997). The disparity of interests between the actors means that the particle physics community has to 'take the plunge' and opt for existing standards which may or may not be adopted by industry at a later stage. This suggests that there is a degree of instability and therefore reversibility in the actor network where standards and technologies are immature. This also illustrates the socio-technical complexity of standards.

This points to a particular need to create a set of standards to enable interoperability, whilst maintaining a level of flexibility within the information infrastructure in order to accommodate for necessary changes. This dilemma can be said to characterise the development of an information infrastructure, like the Grid where actors' interests, the development of technologies and standards and so forth is in a constant state of flux in an attempt to align and realign according to their interests. This is especially the case where the underlying sets of standards are in the process of being defined. It follows that there is a great deal of uncertainty about how the actor network develops and therefore the way in which the Grid will evolve over time: an information infrastructure is 'open' and therefore enforcing control is difficult.

This has implications for the adoption of the Grid. The lack of standards coupled with the immaturity of Grid technologies/tools exposes end-users to the 'bleeding edge' of a developing information infrastructure. Without the required technical expertise and motivation end-users are currently finding it difficult to adopt the Grid. Moreover, the fact that the particle physics community are involved in the Grid development means that they are encountering the most difficult problems. It is therefore not surprising that the community has some scepticism about whether the Grid will improve on how they carry out their research. Moreover, to adopt the Grid may require a change in the existing 'formative context' (Ciborra & Lanzara 1994) which by implication will take time. Therefore, we can speculate, that the adoption of the Grid may only result out of necessity. Some attempts are being made by

GridPP to address these issues by appointing a public relations officer to improve the communication about Grid developments and improvements. It follows that standards and Grid technologies will have to be developed sufficiently in order to attract a wider user-community.

8. CONCLUSION

The aim of this paper was to uncover the issues and challenges of developing an information infrastructure. We believe that this has been achieved. By drawing on the many socio-technical elements that make up the Grid, we have been able to illustrate that developing an information infrastructure is not a straightforward process. In this way we have been able to illustrate how an information infrastructure can be conceptualised as an actor-network. From a macro-level perspective, the importance of standards has been highlighted without which it is difficult to have a user community and subsequent adoption of the Grid. Moreover, some of the frustrations of developing an information infrastructure may have to do with the tension between standardisation and flexibility; at the early stages, it is difficult to know ‘what to be flexible over and what to standardise’.

In addition, we have outlined the significance of the particle physics community ‘being first’ in terms of establishing an installed base including technologies, standards, experience with some discussion on how the context and history shapes Grid development. It follows that the socio-political realities have been taken into account as they provide an important backdrop in conditioning actors.

Considering the notion of the strength of inscriptions has allowed us to specify which lead to disciplining use: this gives a different perspective to the notion of ‘politics’ and ‘power’ (Hanseth 1997). Although this was fairly obvious in actors aligning their interests for purposes of constructing the Grid, the macro-perspective view of the subsequent and ongoing development of the Grid gave us few surprising insights. However this concept has certainly emphasised the socio-technical complexity of an actor network.

Although an actor network was formed and made durable around the need to construct the Grid, there is sufficient instability within the Grid in terms of technologies and standards that makes the future ‘unpredictable’. It will be interesting to observe how various inscriptions will surface and how they will come to be translated and effectively steer the Grid development in a certain direction.

9. LIMITATIONS AND FURTHER RESEARCH

The size of an information infrastructure (Hanseth 1997) makes a detailed and an all-inclusive study challenging, if not all together impossible. The particle physics Grid in the UK is made up of many actors-many of which have not been discussed in this paper (eg Microsoft, W3C, digital certificates). As Star (1991) posits, in analysing an actor network, it follows that there are other actor networks that will be marginalised. Based on the notion of a scalable actor, it is a matter of convenience and not principle which 'black boxes are opened and which are not' (Hanseth 1997, Monteiro 2000). In order to provide an unbiased insight into how the information infrastructure is developing it has been necessary to rely on the concept of being able to 'zoom in and out'-a systematic study would have limited this work.

The research has been approached largely from a macro-perspective. It is felt that at times, to enrich the area of study, a micro-perspective would have been beneficial. For example, more detail on some of the specific technical actors would have been relevant for this research as often, IS research is criticised for not giving enough attention to the technology (Orlikowski & Iacono 2001). It would have been interesting to consider more specifically how the 'technical mesh with the non-technical' (Hanseth et al 1996).

It follows that it has been difficult to follow a series of inscriptions in strengthening an actor network. This is partly due to the broad scope provided and the limited amount of time available within which to uncover more detail to illustrate the concepts of inscriptions and translations over time. Therefore, in some cases, it was difficult to assess the relative strength of inscriptions followed by translations. In retrospect, in using this minimalist version of actor network theory, it would have been beneficial to focus on a particular area of Grid development in some detail. Although the strength of inscriptions was illustrated in how the actor network formed around needing to construct a Grid, this was not so obvious in describing the subsequent ongoing development. Some inscriptions were highlighted with a limited view on whether or not these resulted in a subsequent translation.

From this perspective, ANT has been criticised for presuming actors to be rational and strategic (Monteiro & Sahay 2000). However, Latour (1999) argues that the equal treatment of humans and allows for a 'diluting of intentionality, responsibility and accountability'. Moreover, in general actor network theory has been criticised for being apolitical and lacking in an evaluative stance (Walsham 1997). In spite of these criticisms, actor network theory provides 'a new methodological and theoretical device to enable us to think about hybrids of people and information technology' (Walsham 1997). This is increasingly important as information technology and communications becomes an integral part to daily life. As has been demonstrated throughout this paper, the development of the Grid is a complex socio-technical process and actor network theory illustrates these concepts well.

The Grid is a new area of research for the IS field. This makes it an exciting time to carry out research into the Grid and the many 'unchartered' social science topics. For example, it would be interesting to investigate issues of trust from the perspective of the virtualisation of the 'intimate relationships between organisational and resource-sharing structures' (Foster& Kesselman 2004). New concepts of the 'organisation' as we see it today are likely to be redefined. This poses a very relevant question: what does this mean for our organisations and institutions today?

It will be interesting to research how the Grid will come to be adopted by the science community, namely by the Life Science community. It has been highlighted that the end-user community in

particle physics has not adopted the Grid. How will this happen for the particle physicists and how will this happen for the rest of the science community?

Moreover, it will be interesting to observe the development of standards for the Grid in some detail: the community is surrounded by a 'sea of standards' and a 'sea of standardisation bodies' and industry players with vested interests-how will standards eventually come to be defined and agreed? Who will be the winners and the losers?

Whatever the area of research, IS researchers will find this an exciting time.

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11. GLOSSARY & ACRONYMS

API	(<i>abbr.</i>) Application Programming Interface An API defines how programmers utilise a particular computer feature. APIs exist for windowing systems, file systems, database systems and networking systems.
DMTF	(See: http://www.dmtf.org/home) Distributed Management Task Force: responsible for leading the development of management standards/integration technology for enterprise and Internet environments.
GGF	(See: http://www.gridforum.org) Global Grid Forum: global standardisation body for Grid computing.
Globus	The Globus Project provides a software toolkit that make it easier to build computational Grids and Grid-based applications.
GridPP	Grid for Particle Physics A collaboration of UK Particle Physics Institutes.
Grid Service	A web service supports the Open Grid Services Infrastructure (OGSI) standard. (Foster et al 2004)
LHC:	Large Hadron Collider
Middleware	Low-level software that enables the fabric (computers, storage and networks) to intercommunicate and allows the sharing of these resources via common Grid protocols.
Oasis:	(See: http://www.oasis-open.org/home/index.php) A non-for-profit consortium that drives the development, convergence, and adoption of e-standards.
OGSF:	Open Grid Services Infrastructure: an integration of Grid and Web technologies that defines standard interfaces and behaviours for distributed system integration and management (Foster et al 2004)
OGSI:	A Global Grid Forum standard that defines the core semantics of a transient Web service, including naming, lifetime, and exposing service state.
Petabyte	One thousand terabytes or one million gigabytes.
PP	(<i>abbr.</i>) Particle Physics.
Protocol:	A protocol is a set of rules that end points in a telecommunication system use when exchanging information. For example, the Internet Protocol defines an unreliable packet transfer protocol. (Foster et al 2001)
Resource: Broker:	Used to virtualise the interfaces to sets of resources.

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- Service:** A service is a network-enabled entity that provides a specific capability, for example, the ability to move files, create processes or verify rights. Service=protocol + behaviour (Foster et al)
- SDK** (*abbr.*) Software Development Kit. 'This denotes a set of code designed to be linked with, and invoked from within, an application programme to provide specified functionality' (Foster et al 2001)
- Terabyte:** A thousand gigabytes
- WSDL:** Web Services Description Language: W3C standard that defines a standard interface description language. (Foster et al 2004)
- W3C** (See: <http://www.w3.org>) The World Wide Web Consortium: develops interoperable technologies (specifications, guidelines, software, and tools) to lead the Web to its full potential.

TABLE OF INTERVIEWS

(In no particular order)

<i>Name</i>	<i>Role</i>	<i>Organisation</i>	<i>Form of Interview</i>
Tony Doyle	Project Leader	GridPP	Telephone: 45mins
Neil Geddes	Director Representative	UK Grid Operations Support Centre PParc; LCG Project Oversight Board	Face-to-face : 2 hrs
Sarah Pearce & Steve Lloyd	PR Officer Collaboration Chair Chairman	GridPP GridPP; Tier 2 Board	Face-to-face: 1.5 hrs
Mark Lancaster	Application/Collaboration Leader	University College London	Face-to-face: 2 hrs
Ben Waugh	Grid Co-ordinator	University College London	Face-to-face: 40mins
Daron Green	World-wide Programme Director for Grid Computing	IBM	Telephone: 2.25 hrs