Problematising the User: A Sociomaterial Account of the Implementation of a Grid for the Large Hadron Collider at CERN [1].

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ABSTRACT

This paper presents an account of the implementation of a grid computing infrastructure among particle physicists at the Large Hadron Collider at CERN. Employing a theoretical framework based on sociomateriality it employs this case to elaborate the role of the user within implementation studies. In particular Andrew Pickering's "Mangle of Practice" is used to demonstrate that, even for such large inflexible infrastructures, the architecture of the system can be negotiated between users and maintainers (a term the paper introduces) tuning the materiality of the system itself. This tuning is found to act as a negotiation which takes place between these parties without direct social interaction. This finding provides a framework for understanding grid and cloud computing in which typically maintainers and users are physically and organisationally separated and thus the materiality of infrastructure may be the only site for such sociomaterial negotiation.

Keywords: Implementation, Mangle of Practice, particle physics, resistance, materiality, Grid, Cloud Computing.

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[1] **Under review in MISQ (Management Information Systems Quarterly). Please do not quote without the permission of the author. Comments are welcome.**

INTRODUCTION

The Large Hadron Collider (LHC) at CERN[2] is attempting to discover the origins of the universe. Vital in this enterprise is a form of distributed computing architecture – grid computing – which was implemented to allow physicists to analyse the vast quantities of data produced by the LHC. Using a case study of this implementation, and employing a theoretical framework based on sociomateriality, this paper extends existing conceptions of the "user" within studies of implementation.

Traditionally, the implementation of an information system is considered as an organisational change process in which a user community is prepared for a new system, and then has the system imposed upon it (Cooper and Zmud 1990; Davis and Olson 1985). Studying such implementation has been an enduring theme within the field of Information Systems since its inception (Churchman et al. 1957; Lucas et al. 2007) and remains central. Recent work has enriched this research by expanding the research context to include a more inclusive biography (Williams and Pollock 2011), extending the focus to include the ongoing process of development (Leonardi 2009; Mackay et al. 2000) and researching both the continued technical and social construction of the IT artefacts within the implementation process.

Leonardi (2009) has highlighted the need for research which blurs the artificial "implementation line" between development (in which the technology is altered) and use (in which social practices are altered) arguing this is an artificial distinction. Indeed contemporary systems development practices (such as prototyping, incremental development and agile development) advocate such ongoing development in use (Highsmith 2002), and, within software engineering, definitions of maintenance include adaptation and improvement

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[2] The Organisation Européenne pour la Recherche Nucléaire www.cern.ch

during use (Pressman 2000). Such ongoing development is important for the increasing implementation of widely distributed computing architectures, such as cloud computing, grid computing, social networking and inter-organisational systems, which are more integrated (Mathiassen and SØrensen 2008), diffuse and interconnected (Chae and Poole 2005) and so demand ongoing development and adaptation.

Research has also highlighted the potential for users to alter technology in use (Leonardi 2011; Orlikowski 1996). Within the implementation literature which has considered users' improvisations and changes to technology, the technology studied is usually flexible (Elbanna 2006), i.e. designed for user-change and innovation within controlled boundaries - e.g. Groupware, Intranets, simulation-software, data-repositories and the internet (Alavi and Leidner 2001; Dodgson et al. 2007; Leonardi 2011; Orlikowski 1996). Research suggests that users can improvise new uses for such flexible technology within their work practices (Barley 1986; Ciborra 2000).Yet while such improvisations can, through subtle recurrent action, lead to major unplanned changes or redesigns of work practices and the technology-in-use (Ciborra 1996; Orlikowski 1996), such changes do not fundamentally alter the fabric and architecture of the implemented system to the hindrance of others and of those managing its implementation. As such there is a gap within such research literature concerning how users altering technology in use may impact other stakeholders of the information system who may not want such change to occur and may themselves be altering or developing the technology.

This paper addresses this gap in our understanding by problematising all the communities involved in implementation (in particular "users" and "maintainers" (a term the paper defines)). Through a theoretical framework based on sociomateriality (Orlikowski 2007) the paper explores how these communities harness material agency in tuning an inflexible grid (as a material artefact[3]) to reflect their intentions – and in particular exploring the impact of such harnessing on other communities' ability to control the implemented system. The paper argues that large distributed infrastructures can entail a form of negotiation for control based around the materiality of the technology.

The paper demonstrates that, at the LHC, the detailed materiality of their grid's underlying software was the grounds for the negotiation of control between users and maintainers. Control here refers to the objectified intentions represented by the ultimately implemented information system (Kallinikos 2005). That is the potency of an individual or community in altering the material artefact, and the potency of a material artefact to influence the individual. It concerns control in material terms within a work practice, rather than control over a social structure (as power). The research question of this study is thus: How do communities come to control a grid during its implementation?

This research question contributes directly to calls for a better understanding of user-resistance within implementation (Lapointe and Rivard 2005; Markus 1983) which has thus far concentrated on factors that lead to user-resistance but has failed to effectively reveal what happens when users resist through material means.

Addressing this research question is particularly timely and relevant for given the acceleration in take-up and use of architectures such as grid computing and cloud computing[4] which are inflexible (they provide the bulk processing of computing jobs based on a simple

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[3] Materiality here refers to both physical and virtual artefacts which have properties in relation to their use. They have substance, matter, and have practical significance and instantiations (Leonardi 2010).

[4] The term cloud computing is poorly defined however we use the term to refer to infrastructure or platforms provided as a service, so called IaaS and PaaS. Estimates suggest that revenues from IaaS may have exceeded $1bn in 2010 (Economist 2010) and IDC estimating the whole cloud market is likely to be worth $56bn by 2014.

interaction with users) and which have a range of communities involved in their development and use with complex relationships between them (Etro 2009; Iyer and Henderson 2010; Lucas et al. 2007). Users of such systems often hold considerable technological expertise (Brown et al. 2007); have "joint IT competence" (Davis et al. 2009, p27), can be engaged in technology implementation and adaptation themselves; and can have considerable opportunity to instigate change through their own software and hardware development efforts. Further such users and developers seldom work closely together during implementation.

In addressing this research question the study directly addresses calls for sociomaterial studies of e-science grids (Orlikowski and Scott 2008). It builds upon the tradition of studying science practices, drawing on seminal studies by Knorr-Cetina (1999) and Pickering (1995) - work which itself highlights the importance of material artefacts within science work practice, with the aim of exploring the role of various communities in the implemented material artefact (in this case grid computing at CERN).

The next section describes grid computing. This is followed by a literature review of implementation and sociomateriality which are used to devise a theoretical framework. The framework draws upon a sociomaterial conception of implementation based on Andrew Pickering's concept of the Mangle of Practice. The following section then introduces the methodology and case study. This is followed by an analysis and discussion of the case, with conclusions presented in the final section.

AN OVERVIEW OF GRID COMPUTING

Improvements in networks and the availability of powerful commodity computing have given rise to distributed computing architectures which enable globally distributed computers to share storage and processing tasks. Various titles have been used to describe such architectures including utility computing, on-demand computing, grid computing (Baker et al. 2002), and more recently cloud computing and Web 2.0 (Cusumano 2010). In this paper we focus specifically on grid computing whose purpose is to provide transparent, seamless and dynamic access to computing and data resources for individual scientists (Chetty and Buyya 2002; Smarr 2004). Grids are very similar to the more commercial (Bandyopadhyay et al. 2009; Natis et al. 2009) and more recent (Foster et al. 2008) concept of cloud computing (Armbrust et al. 2010). Grid extends the computing context from a small group of similar data-centres evident in cloud computing (at companies such as Amazon, Google and Microsoft) to a much more dynamic computing platform "on a global scale" (Foster et al. 2001b). Grid computing was a frontrunner to, and its concepts remain central within, cloud computing efforts (Cafaro and Aloisio 2011; Foster et al. 2008) and hence its lessons are relevant to cloud computing (Willcocks et al. 2011). Both grid and cloud computing involve user communities with considerable technical expertise who are often organised into groups or organisations. In both maintainers and users have little (if any) direct contact.

A computing grid is a "network-based computing infrastructure providing security, resource access, information and other services that enable the controlled and coordinated sharing of resources" (Foster et al. 2001a). It usually consists of a large number of globally distributed computing processors, storage arrays and devices within differently administered sites, linked up and presented to the user as a single computing service without the user needing to consider the individual resources or their location (Berman et al. 2003). In this way it extends the supercomputing idea of cluster computers – large farms of homogenous computers which undertake bulk processing for users – to provide clustering of clusters on a global scale with heterogeneous resources. The computers on the grid run software (called middleware) which allows users to submit processing jobs to the grid without needing to know detail about the underlying system (Plaszczak and Wellner 2007). The Workload Manager System (WMS) is responsible for managing the allocation of these jobs to the different computers on the grid and thus ensures the transparency of the grid to users with respect to the running of their software (Abbas 2004).

Particle physics pioneered the development of grid computing as it is required to analyse the 15 million gigabytes of data per year the LHC produces. Their grid (the LHC Computing Grid – LCG) contains the equivalent of 100,000 computers (Faulkner et al. 2006) and is spread across 140 computer centres (sites) in 35 countries (Britton et al. 2004). Implementing this grid into the scientific practices of CERN physicists was a significant challenge and offers an opportunity to understand the implementation of such infrastructures before their widespread adoption in other areas.

LITERATURE REVIEW OF IMPLEMENTATION

Traditional views of implementation see it as managerially imposed with the aim of change – a technological or organisational imperative (Lin and Cornford 2000; Lyytinen 1999; Markus 2003) with the technology as a potent external force for change either alone or enrolled within wider strategic initiatives (Beard and Sumner 2004; Krell and Matook 2009). This influential thesis suggests implementation is the development or selection of technology within a strategic organisational ambition (Porter and Millar 1985; Taylor 1995) with users as actors within the socio-technical information system being implemented. The "user" is the beneficiary or victim and their involvement in the technology's development is limited to representing and communicating business needs and information requirements – a business-definitional role (Davis et al. 2009). Users are studied as rational agents adopting (or failing to adopt) a fixed technology (Davis 1989; Shang and Seddon 2002) and such research focuses on contingent factors (Sharma and Yetton 2003) such as ownership (Barki et al. 2008), user-engagement (Chan and Pan 2008), user-satisfaction (Wixom and Todd 2005), status-quo bias (Kim and Kankanhalli 2009), and trust (Leimeister et al. 2005).

Implementation has however also been researched as a social and political phenomena (Markus 1983; Walsham 1993) concerning the needs, interests and capabilities, and collective interpretation of the system (Fulk et al. 1987, p537; Gal and Berente 2008) , the social structures of users within the organisation (Joshi 1991) and the organisation as an institution (Avgerou 2000; Avgerou and McGrath 2007). Power is a prominent feature of such research, focusing on the impact of implemented systems on the power and control of information by different stakeholder groups (Azad and Faraj 2010; Dong et al. 2009; Doolin 2004; Keen 1981; Keen 1991; Kwon and Zmud 1987; Thong et al. 1996) but these studies lack consideration of the users' power towards the implemented system as a material artefact.

Orlikowski has argued that such studies should be enhanced through an explicit focus on the IT artefact within the social context (Orlikowski 2007; Orlikowski and Iacono 2001) and through reflecting the wider "practice turn" within social theory (Schatzki et al. 2001) in which "the social is a field of embodied, materially interwoven practices centrally organised around shared practical understandings" (Schatzki 2001). Implemented technology is a "stranger" who must be made sense of and responded to within the doing of work (Ciborra 1999). Implementation 'reveals' technology as distinct for that particular context through an emergent process (Orlikowski 2000). Users improvise, innovate and adjust to the new technology over time (Barley 1986; Ciborra 2000; Zuboff 1988) and such research identifies subtle micro-processes that are enacted as users appropriate new technology, experiment with it innovating locally, and improvise "cognitive and normative variations to accommodate their evolving use of the technology" (Orlikowski 2010 p133).

Yet such studies can also lead to minimizing or simplifying the role of technology, "sidelining the physical characteristics and capabilities entailed in particular technological objects" (Orlikowski 2010 p133). Such studies treat the implemented technology as a case of technology adoption, diffusion and use, each as a separate and distinct phenomena (Orlikowski 2007), and hence downplay the affordances, constraints and capabilities of the IT artefact itself, instead privileging the human actor within the context (Berg 1998; Rose and Jones 2004). What is lost is the capability to posit and theorise the material effects of technological artefact (Orlikowski 2009). Further, such studies tend to assume an ultimate stabilisation of technology rather than considering them as being constantly modified in use (Wajcman 2000; Woolgar and Cooper 1999).

SOCIOMATERIAL ENTANGLEMENT.

Responding to the above concerns, over the last decade a number of sociological and science and technology studies perspectives have emerged based on an ontology of entanglement (Barad 2007; Orlikowski 2007) in which the social and material are considered intertwined or imbricated (Ciborra 2006; Leonardi 2011). Within implementation research such studies have mostly employed either structuration theory (Dong et al. 2009; Juan et al. 2009; Zahid and Nelarine 2009) or Actor Network Theory (ANT) (Elbanna 2010; Shepherd et al. 2009).

This paper explores the enrolment of material agency[5] within the practices of communities involved in the implementation of a grid using a theory ontologically consistent with these two approaches (Jones 1998) and which draws upon their key insights (Chae and Poole 2005; Jones 1998; Rose and Truex 2000) but which is particularly relevant to researching users' negotiation of control of an implemented system through harnessing material agency over

[5] This paper defines material agency as the capacity for material artefacts (including technology and software) to act independently from human intervention – their performativity through "the things they do that users cannot completely or directly control" (Leonardi 2011).

time. This theory reflects the practice based ontology evident in many studies of science (Barad 2007; Knorr-Cetina 1999) and sociology (Barad 2003, Latour 2005, Suchman 2007).

Andrew Pickering's Mangle of Practice (MoP) (1993; 1995) is based on temporally emergent actions in which intentionality is restricted to the human and which focuses on the harnessing of material agency within practice. This theory is uniquely relevant to this study as it provides a strong view of material agency which is not simply semiotic (with agency as "a material-semiotic attribute non locatable in either humans or non-humans" (Suchman 2007:261) as ANT might suggest with "its location of agency in texts and interpretations"(Jones 1998)) but directly influences human actions – machines can do things. But crucially such machines do not have a mind of their own (Jones 1998; Pickering 1993). Unlike ANT, the non-human actors are not subjective, intentional or even moral (Rose and Jones 2004). Only humans can hold intentionality (something ANT has difficulty ascribing (Chae and Poole 2005) due to its lack of distinction between human and non-human (Leonardi and Barley 2008)) and material agency must thus be delegated (Jones 1998) to act for humans (as a speed-camera acts based on human intentions), or act unintentionally (as lightening acts without intention). This view of agency allow the study to explore users' intentions towards technology within implementation as sociomaterial, and to explore users enrolment of technology in controlling the implementation, without either over privileging human agency (as structuration theory can (Orlikowski 2005; Rose and Jones 2004)) or over privileging material agency (as ANT can (Jones 1998)).

The MoP has been used in a range of fields including environment studies (Franklin 2008), gender studies (Guzik 2008), economics (Sent 2008) and information systems (Barrett et al. 2011; Chae and Poole 2005; Jones 1998; Marick 2008; Rose and Jones 2004). The MoP itself emerged from the detailed study of the work practices of particle physicists and their development and use of technology.

We now describe the vocabulary of the MoP – defining the analytical terms used within this paper: practice, intentionality, human and material agency, material artefacts and community.

Practice

Practices, in this study, are actions undertaken by humans with an intended purpose and in which material objects are handled and moved, and things are described or understood (Reckwitz 2002). They are "matters of doing/acting that perform particular phenomenon" (Orlikowski 2009). Unlike studies of practice as routine and habitual action (Feldman 2000) for this study practice must be understood as dynamic, *ad hoc*, creative and constructive, in which humans respond to the world of objects (Knorr-Cetina 2001) as experts re-employing their knowledge for an intended purpose. As such intentions of implementation practices of all those involved are analysed within this research.

Some work practice is not, however, wholly emergent and creative – it also occurs within social structures which exert influence on it and lead humans to undertake certain practices as specific "machine-like actions" within an established conceptual knowledge (Pickering 1995, p115). Such influence is termed "disciplinary agency" as it is human but also machine-like, lacking specific intentionality. For example, the practice of doing algebra is machine-like – it is neither routine, nor innovative, but instead is constrained by the disciplinary agency of algebraic rules.

Intentionality

Within this study intentionality is limited to humans. Drawing upon the MoP, intention is the everyday sense of practice being organised around specific plans and goals. Intentionality then is an endpoint – a focal purpose which is "temporally enduring" relative to the practices that occur, "a relatively fixed image of some future state" (Pickering 1993), and exists in chains of smaller intentions linking immediate action with future intention (Dant 2005). They are "imaginatively transformed versions of the present" constructed from the present by a process of "modelling" (Pickering 1995). Such modelling is an open-ended process without determined destination – it concerns an imagined purpose, and imagined steps which may move towards such purpose. But intentions are also emergent and "can themselves be transformed in, and as an integral part of, real-time practice, which includes sensitive encounters with material agency" (Pickering 1995, p20).

Human and material agency: The mangle of practice.

In achieving their intentions, individuals bring their agency to bear through their development and use of machines and objects within their practices so altering the sociomaterial assemblages of their practices. However, sociomaterial assemblages offer **resistances** to such actions in the form of material agency (for example the Mississippi river resists attempts to control its flow by rising ever higher (Pickering 2008)) to which humans must respond with **accommodations** involving the further development of technology and objects (building higher levees for example (Pickering 2008)) with the aim of achieving their intentions (though further material resistances might obviously follow). Work, therefore, involves manoeuvring "in a field of material agency, constructing machines that (…) variously capture, seduce, download, recruit, enrol or materialise that agency, taming and domesticating it, putting it at our service" (Pickering 1995, p7). Through the unfolding of resistance and accommodation, human and material agency are constitutively enmeshed – they emerge (Pickering 1993) within a dialectic which Pickering terms the "mangle". Dialectic here refers to a Hegelian dialectic as a theory of motion within a phenomenological ontology. Within any given situation there exists its own negotiation – a tension and interplay which produces constantly new and emergent forms of social existence. There is no material-intentionality since it cannot be separated from human agency within this dialectic. The focus of this research is thus decentred from the human (Pickering 1995) and the material, to instead focus upon the human-material "mangle". The mangle has two meanings: the first is when human and material are squeezed together over time (as a washing-mangle squeezes clothes between rollers). The second is a violent confrontation like a car being "mangled" in a crash. Radical changes occur to practice and technology as resistances are accommodated in ways which alter the material world.

Machine configurations (such as grids) are the outcome of a "**tuning process**" (as in tuning a radio) whereby they are "harnessed", "directed" and "domesticated" within the flow of material agency so stabilising both the material and human agency (Pickering 1995, p278) towards a human intention. However, such "tuning" only stabilises and ceases once it leads to outcomes which make sense to the humans and aligns with their intentions, and until this occurs humans interpretive accounts and practices continue to evolve (Pickering 1995, p81). Artefacts' purpose cannot be pre-specified or designed (see (Pickering 1999) for an illustration of this). The Mangle is a linear account of tinkering (or "trial and error" (Pinch 1999)) making it highly appropriate to the study of implementation which has itself been described as "tinkering" and "drift" (Ciborra 2000).

Material artefacts

Within this mangling of practice, material artefacts' purpose and use are enrolled and mangled in use: a view which reflects Gibson's notion of affordances (Gibson 1979; Hutchby 2001) and provides a focus on the capabilities and constraints of the technical artefact being implemented. The human actor works, not with pre-given specifications of technology, but with "meaning conceptualisations of the aspect of the material world" which, through experimentation, they explore and transform, and in doing so alter their own interpretive accounts (Pickering 1995, p81). The implemented technology is thus the outcome of the stabilising of mangling human and material agency, in which a range of actors are engaged (including so-called “users”).

Community

What is not articulated in Pickering’s work is how accommodations within the sociomaterial practices of individuals become learnt and accepted practices within a wider community (Pinch 1999) and thus form disciplinary agency. To fill this gap, this paper looks to a theory of learning which is consistent with the practice based theory of the MoP, but which focuses upon the sharing of knowledge within a collective, and thus the learning of a discipline. This paper adopts the view that learning is a social participatory activity (Lave and Wenger 1991) through which social structures, termed communities of practice, emerge. Such communities of practice are emergent configurations of individuals (Wenger 1998) sharing an emerging disciplinary agency. They are unstable social configurations as the practices of individuals change. This study however adopts a slightly different concept of communities which aligns with the collective view on the Mangle of Practice – they are learning communities (very similar to communities of practice) whose members share an intention within their work practice with respect to a shared information system, and which share knowledge, just as a community of practice might, in order to collectively achieve the aims of such broadly shared intention. Such communities are also reflective of occupational communities (Bechky 2003) in that they are structured by the work undertaken and have differing sub-cultural understandings of their work.

In the next section we introduce the methodology and case study. This case is then analysed through the concepts identified above.

METHODOLOGY AND CASE STUDY

An in-depth, qualitative field study was conducted between 2006- 2010 of the implementation of the LCG by the UK and CERN particle physics community in preparation for, and upon the launch of, the LHC. The setting was chosen for both theoretic and pragmatic reasons. The research team had been funded by a UK research council to undertake a long-term qualitative study of this community[6]. CERN was particularly relevant to addressing the research question for the following reasons. CERN's grid was a global emerging system and the largest of its kind (Economist 2005) with large global collaborations involved in implementing and using it. Users and maintainers were globally distributed and had little face to face interaction. CERN has a reputation for developing and using advanced computer systems, including having invented the Web, and experimental physicists at CERN are all highly competent in computing and regularly develop new systems. Users' interaction with the LCG was through a command-line interface which allowed explicit observation and discussion about using the grid since the scripts were easily observable.

This single case study of implementation was appropriate as it allowed a deep understanding of the IT artefact in its socially embedded context (Orlikowski and Iacono 2001) and detailed observation of individuals' responses (Klein and Myers 1999). The purpose of the case was not theory testing, but to employ the theoretical framework as a sensitizing device within our analysis (Klein and Myers 1999). The case study is employed interpretively (Myers 1997; Walsham 1993) with the aim of using the theoretical framework to surface issues.

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[6] See [SITE REMOVED FOR ANNONYMITY] for more details of this effort.

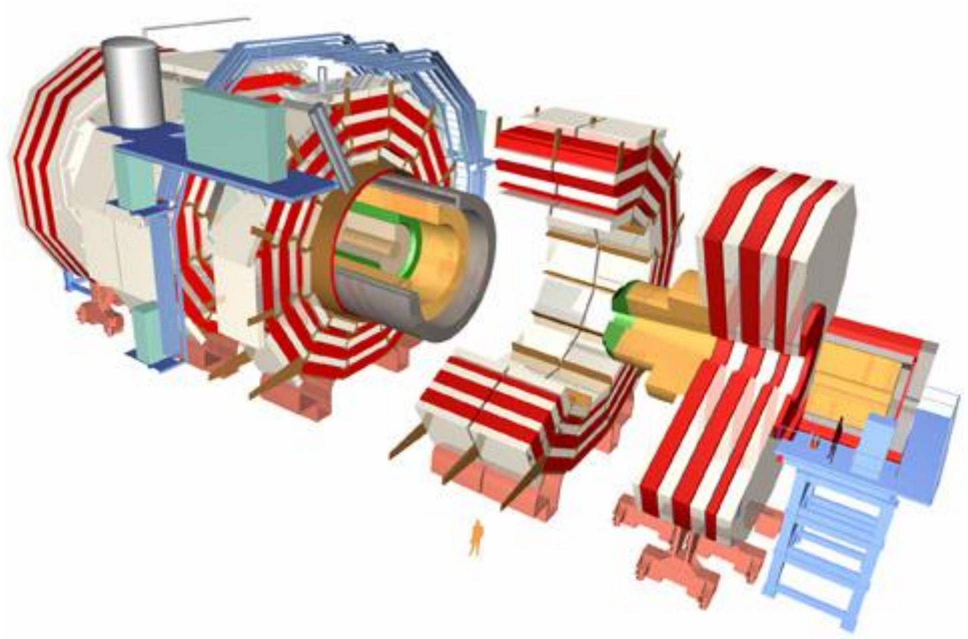

Figure 1: The CMS experiment (exploded view – figure at bottom shown for scale)

In limiting the scope of the case to a manageable yet meaningful scale, the study focuses on those involved in developing and maintaining the LHC Computing Grid (LCG) for all experiments at the LHC, and on physicists from only one of the LHC's four experiments **-** the Compact Muon Solenoid (CMS) experiment (Figure 1). The CMS collaboration consists of around 3000 scientists and engineers from 159 institutes in 36 countries developing, running, and analysing data from this CMS experiment.

Data collection

Data collection was through sixty interviews (recorded and transcribed); observation of weekly UK project-management-board meetings of those involved in the LCG implementation within; attendance at five two-day meetings, two conferences, numerous site visits and social events and two week-long visits to CERN. Analysis was undertaken of documentary sources associated with LCG and CMS, in particular the extensive wiki pages, journal articles, websites, various user configuration files, and the CMS offline analysis workbook. This 409 page soft-bound handbook is given to each physicist within the CMS collaboration and provides a comprehensive manual for doing physics analysis using CMS data. The researcher undertook one-to-one training sessions on physics analysis and on running analysis jobs, and on the grid's management. Four LCG data-centre machine rooms were observed. The researcher also reviewed grid log files to understand particular grid operations.

The choice of interviewees aimed to be representative of the range of jobs descriptions and seniority levels within CMS and LCG. For pragmatic reasons, interviews were mostly of CMS and LCG members associated with UK institutions (though not necessarily based in the UK) or working directly at CERN. This limitation does not significantly affect the findings as UK participants are highly active within CMS and LCG – with the UK providing the greatest contribution to the LCG at the time of this research. UK institution's participants are international reflecting the diversity evident at CERN.

The corpus of data was analysed in an interpretive and flexible manner by developing organised themes and issues guided by the theoretical framework and in keeping with Walsham's approaches to interpretive research (Walsham 1995; Walsham 2006). The researcher sought to focus on analysing the sociomaterial practices of LCG and CMS and considerable effort was put into understanding the detailed technical practice of physics analysis. A subsequent round of interviews was undertaken specifically to explore the emerging themes of implementation and these were further analysed. The case was presented to UK members of LCG (including a number of CMS users) at a meeting in April 2009 to help validate the case study, and gain feedback. Further interviews were then undertaken to clarify particular points and to triangulate the findings.

The case study is elaborated and enriched using quotes taken from the individuals in Table 2. These quotes were chosen to effectively represent the range of views. Additional quotes and evidence are provided as endnotes to enrich the case study but not detract from its flow.

Table 2 – Key Interviewees from whom quotes are taken.	
Code	**Job description**
P1	CMS representative to UK LCG development (GridPP).
P2	Post-Doc Research Assistant undertaking physics analysis on CMS
P3	Post-Doc Research Assistant undertaking physics analysis on CMS
P4	Overseer of grid middleware development for LCG and systems administration.
P5	PhD student undertaking physics analysis on CMS
P6	Software developer Involved in middleware development and systems administration based at CERN.
P7	A previous senior manager of the integration of experimental software with grid services.
P8	Senior representative of LCG with oversight over LCG implementation. Also a particle physics professor.
P9	Lecturer in Particle Physics and CMS user – also represents CMS to LCG.
P10	Developer of LCG grid monitoring application
P11	Manager of a data-centre within the LCG and senior LCG member. Previously a particle physicist.
P12	Interviewee responsible for documenting grid usage
P13	Individual leading the development of the grid information and monitoring infrastructure
P14	Senior developer overseeing the development of CRAB within CMS
P15	CRAB developer with physics background but not in CMS. Worked within a CMS physics group.

CASE FINDINGS AND ANALYSIS: THE PARTICLE PHYSICIST ENGAGING IN GRID PRACTICES

Background to undertaking analysis of CMS data at the LHC

Expanding humanity's knowledge of particle physics involves recreating the conditions just after the universe's "big-bang" within an experiment. Such conditions can be recreated by colliding hadrons (in this case protons) at close to the speed of light. For this purpose physicists constructed the 27km LHC particle accelerator ring and four physics experiments (ATLAS, CMS, LHCb and Alice) within which these collisions occur and are recorded. CMS seeks "new physics results" from these recordings including searching for the Higgs boson[7],

[7] This standard model of particle physics has been extremely successful in describing particle physics data since its formulation in the 1960s and 70s. However the model requires the existence of a particle called the Higgs Boson, and hence the desire to discover this is extremely strong - though for many physicists proving it doesn't exist would be much more interesting!

an extremely elusive particle which (if it exists) can only be found by creating vast numbers of very high energy collision events . A trigger system sifts out potentially interesting events from the 31million produced per seconds so that data recording is limited to 2GB/s, with 1Mb of data per event stored. Analysing these collisions is challenging as the data is extremely complex and understanding the effect of the detector is difficult. Particle physicists must thus distinguish new physics results from the general messiness of the data. They do this by comparing real data from CMS with simulated “Monte Carlo” data to look for discrepancies. This simulated data is produced using a software simulation of CMS based on currently understood physics models.

Both reconstructing the raw signals from the experiment, and simulating and reconstructing the Monte Carlo require massive computing power. However as events are independent the software can run in parallel on the computers of the grid. The grid middleware must thus break the job down into potentially millions of parallel jobs, identify the relevant files, submit the software and files to available processors, then ensure all ran successfully and recombine the final result. Alongside such high-performance computing services the LCG must also provide support services– including user support, accounting, security, logging services and change control.

Introducing a grid for CMS.

Drawing upon the theory of learning communities (defined in the theoretical framework above) it is possible to identify two communities defined by their intentions towards the grid being implemented. These communities are analytical device and members did not hold specific organisational memberships or job titles which defined their membership, however their occupations and work practices were somewhat aligned, they held similar cultural understanding of their work, and they learnt from each other. The LCG acted as a boundary object (Star and Griesemer 1989) between these communities, and some individuals spanned both communities – for example the CMS representative to LCG. These communities were not strongly bound by managerial hierarchy (Traweek 1988; Zheng et al. 2011) and thus the implementation of the LCG was not strongly driven by a strategic or managerial imperative. This is not to argue that power and politics did not exist within and between the communities, but rather they were sufficiently limited to allow the study of other aspects (Knorr-Cetina 1999; Traweek 1988; Zheng et al. 2011).

CMS-Physicists were those physicists who undertook physics analysis using the LCG grid within the 3600 people strong CMS collaboration . All held, or were working towards, a PhD and were often "arrogant" about their intellectual prowess (Hermanowicz 2009; Knorr-Cetina 1999). They were pragmatic, organised and highly collaborative (Knorr-Cetina 1999), constantly discussing practices and ideas. Skilled in computing they undertook data analysis by writing C++ software and UNIX scripts that used libraries of statistical functions developed by CMS and the wider particle physics community. Their shared intention in using the LCG was focused on CMS as a collective discovering "new physics" quickly (ahead of ATLAS their rival experiment at CERN). Individuals held personal plans and goals such as undertaking a specific analysis for a paper, developing a simulation, or gaining a PhD; though these collectively aligned with the shared intention of CMS. The LCG was a computing resource they had to use to access data, run analysis jobs on that data and produce graphs. The grid was just the latest brute-force processing system to analyse their events and was uninteresting, even boring. Their identity was shaped by the CMS collaboration and the importance of doing physics. Among them a subset wrote software to help them do their work more effectively and CMS employed a small number of dedicated software developers to help in this task. As a community of thousands they seldom met as a whole – instead holding smaller specialist gatherings on particular topics.

LCG-Gridpeople saw most of their contribution to CERN as the production of an effective shared computing resource for all LHC experiments (Zheng et al. 2011). They were composed of both academic particle physicists and computing specialists. The specialists only worked on the computing effort and undertook no physics analysis, though many had a strong physics background. They held job titles such as Computing Engineer, HPC systems administrator, Production Manager, Application Support officer. The particle physicists, were academics (or students) who believed that, for the good of the LHC as a whole, they should work on providing a shared grid resource alongside their own physics research. This community met and communicated regularly (including meetings attended by hundreds) to develop the LCG and were highly collaborative. The size and scale of the computing resources was an important part of their identity, particularly the 140 global computing centres making up the main grid resources and the large CERN computing facility. Often somewhat ignored and marginalised, they aligned themselves strongly with the grid development and were under considerable pressure to provide an analysis resource.

Introduction to physics analysis

The case study is of the period shortly after the LCG was introduced into the working practices of CMS-Physicists. LCG was implemented slowly, with early releases followed by continued development in use. Similarly, the use of LCG by CMS increased slowly as demand for computing outstripped the existing resources and people were forced to use the grid for their analysis.

In general, CMS-Physicists simply wanted a processing resource which would undertake their analysis jobs quickly[i]. When the LCG was introduced it proved difficult to use as it demanded a new approach to packaging and submitting analysis jobs when compared with the existing cluster-computing. CMS-Physicists complained about its strangeness and inconsistencies. LCG-Gridpeople, aware of this, responded with improvements to the system and with training and documentation. The time taken to learn these new practices was however resented.

Faced with this challenge, some CMS-Physicists developed their own interface software reflecting their specific intentions for undertaking CMS analysis. This software mediated between CMS-Physicists and the LCG[ii] when they undertook CMS analysis. One of these pieces of software - CRAB (CMS Remote Analysis Builder) – is the specific focus of this case study. CRAB was "intended to simplify the process of creation and submission of CMS analysis jobs into a Grid environment" (Heavey et al. 2006) and provide an "analysis wrapper" (P15) around the grid[iii]. CRAB was complex and sophisticated software undertaking sophisticated interaction with the LCG in order to run the jobs (See figure 2).

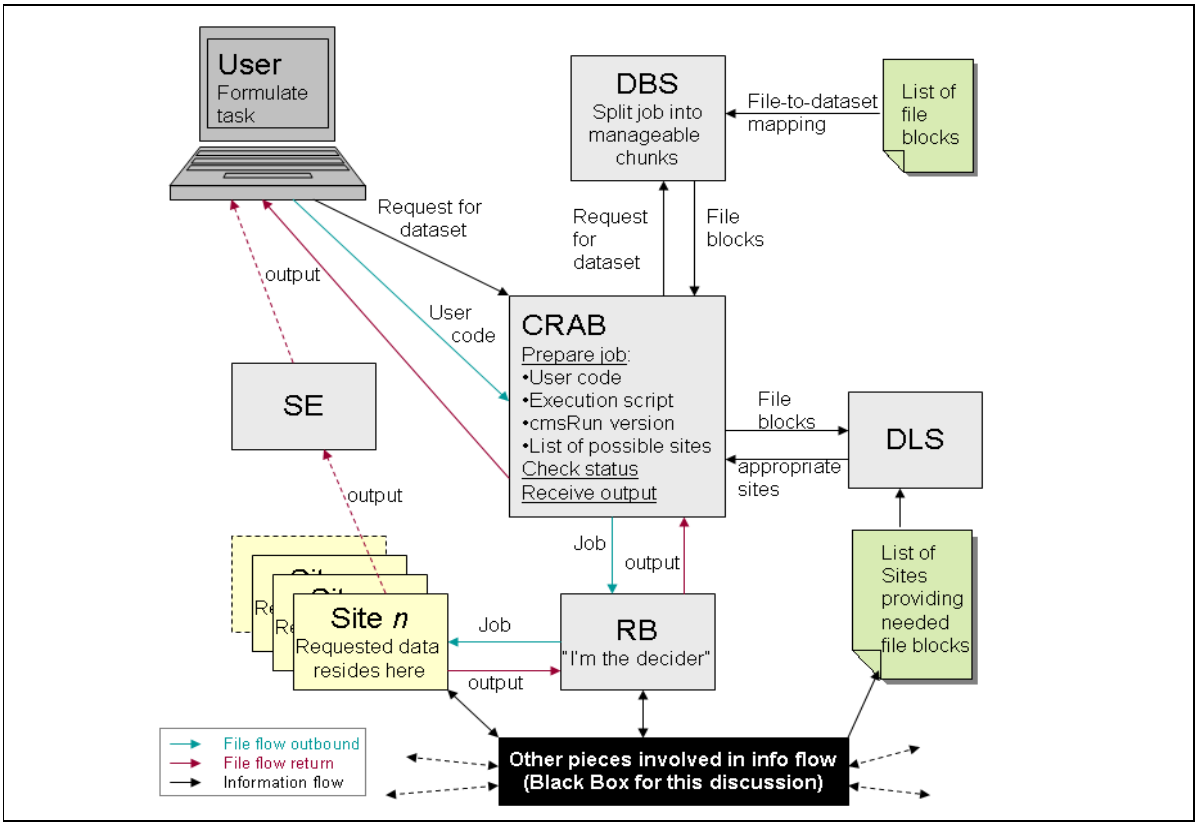

Figure 2: Executing a job for CMS: (Heavey et al. 2006). Taken from the CMSOffline analysis workbook, this diagram outlines how CRAB interacts with the grid Resource Broker (RB), the Data Location Service (DLS), and the Dataset Bookkeeping Service (DBS) (collectively these make up the WMS Workload Manager) to prepare a job for execution on sites, and to move the results to a storage element (SE).

Requirements for the CRAB software came from among the physicists themselves[iv]. Using CRAB involved specifying in a text file (crab.cfg – see figure 3) the parameters of the job. The CRAB software then packaged the analysis jobs and instructed the LCG to run them using CMS data.

```
[CMSSW]
total_number_of_events  = -1
number_of_jobs          = 10
pset                    = reco_RECO_tsw.py
datasetpath             = /Boosted_Quark_To_ee_2TeV/tsw-my5e32HLT_2-00TeVu_v1-
5c8626423b3ca515cf3687fd35dfb13a/USER
dbs_url                 = http://cmsdbsprod.cern.ch/cms_dbs_ph_analysis_01/servlet/DBSServlet
output_file             = mcFile_GEN-SIM-bothRECO_spec412ReconV2.root

[USER]
ui_working_dir          = crab_bstd412Recon_2-00TeVu_v2
return_data             = 0
email                   = XXX.XXX@cern.ch

copy_data               = 1
storage_element         = T2_UK_SGrid_RALPP

publish_data            = 1
publish_data_name       = bstd412Recon_2-00TeVu_v2
dbs_url_for_publication = https://cmsdbsprod.cern.ch:8443/cms_dbs_ph_analysis_01_writer/servlet/DBSServlet

[CRAB]
scheduler               = glite
jobtype                 = cmssw
use_server              = 1
```

Figure 3: Example fragment of a CMS PhD student's Crab.cfg file. Note the email address of the user has been obscured.

In order to help other CMS-Physicists learn to use CRAB its developers organised training sessions which doubled as requirements capturing events[v]. Most CMS-Physicists were however uninterested in the complexity of CRAB or LCG and disliked (and often avoided) attending training courses on it or the LCG (as a manager explained "Users don't go to [training sessions], they don't want to talk to a bunch of geeks" (P8)). Instead they usually relied on “word of mouth” and tailoring existing working scripts[vi], by referring to websites of FAQs, the CMS documentation, and various Wikis[vii] and Websites to resolve problems (though seldom were these resources used to learn the initial steps). Unlike user interaction with mouse based software, crab.cfg files afforded being read and could be emailed to others to gain help and advice.

New users were initially given a colleague’s crab.cfg files to experiment with. Within groups “power-users” (P14) emerged who shared a “kind of base configuration” with those working around them “just adding a few things” (P14). As a senior CRAB developer explained “they are learning on the fly... All is pretty easy to do, it’s just a matter of seeing it done a couple of times, probably once, and then you don’t need to spend a lot of time on that kind of thing” (P14).

Once working, a user’s crab.cfg file would form part of their standard practices – it would have small modifications for each new analysis job, but was seldom drastically altered unless it began to hinder the analysis task. CMS analysis therefore involved CMS-Physicists modifying their crab.cfg file and submitting their jobs through CRAB.

The LCG grid resists.

As the LCG continued to be developed post-implementation, inevitably things went wrong with grid jobs – particularly as physicists began regularly running millions of them.

LCG-Gridpeople intended (in line with the concept of grids) that physicists should not know about the underlying operations of LCG. Grids are intended to be seamless and transparent and when working correctly the Workload Manager System (WMS) should automatically send jobs to available resources, and re-submit jobs to other resources if they fail. This WMS is also used by the LCG-Gridpeople to ensure the effective operation of the grid as it allowed them to exclude ("black-list") sites from the grid which are not working correctly, and to target jobs at specific sites ("white-list") for testing purposes[viii].

From an LCG-GridPeople's perspective the role of the WMS was thus to allocate jobs to machines on the grid - not necessarily to ensure they ran correctly on that machine. A grid success was the condition where the grid ran something, even if the job crashed, took a very long time, or problems occurred. This was logical as allocating jobs to a grid is extremely complicated (Avellino et al. 2003b) and identifying when a job has ended abnormally is difficult (Avellino et al. 2003a). Reflecting this, the LCG returned a so-called "zero-code" (meaning success) in all cases where the grid had run something – whatever the result. LCG-Gridpeople did not see it as vital that CMS-Physicists faced with difficulties in job submission (such as zero-codes for failing jobs or jobs disappearing "into a black-hole" (P15)) understood grid problems as they provided support through a global support management system called GGUS (Global Grid User Support) .

From a CMS-Physicists perspective zero-codes were unhelpful; "job-success was always zero...no matter what happened... This is just not very useful for physicists. For one thing it is impossible to monitor if something is going wrong" (P2)[ix]. CMS-Physicists were unclear of the purpose of GGUS and were reluctant to use it. They were disinclined to search for support unless problems were recurrent, and they avoided GGUS as it did not provide direct contact to local individuals as previously available (because the grid is globally distributed and so such roles were also distributed), and was often slow to respond[x]. Worse the use of CRAB software inhibited the use of GGUS. Many "CMS users see CRAB as the grid, they don't care about the fact that there is a big infrastructure underlying CRAB. Every kind of issue on the GRID became a problem with CRAB" (P14). LCG-Gridpeople did not understand CRAB and so GGUS was unable to provide support for this: "the grid people don't know what I am talking about because I am talking CMS language and the CMS software people say it is a grid problem." (P3). Some CMS-Physicists also failed to understand that the grid was failing their jobs and instead often blamed the CRAB software – "there is a school of thought that the last letter should be changed to P" (P5)[xi].

CMS-Physicists expected to be able to fix problems themselves (as they had with previous systems) and CRAB software provided error messages to help them in this (though most messages were only of use to LCG-Gridpeople[xii]). Faced with such resistance from zero-codes, CRAB and the grid, many CMS-Physicists experimented with the CRAB "Kill" command to remove jobs from the grid. They could then stop jobs which seemed to take much "longer than the rest" (or if they had made a mistake[xiii]), then simply run those jobs again. Here 'longer' was subjective, often suggested as the time it takes for a coffee, while the last jobs at night might be given 12hrs before being killed.

Black-list and White-list within CRAB

Faced with the problems of zero-codes, job failures, waiting for failed jobs, and poor user support, the CMS-Physicists developing CRAB extended it (based on their communities feedback) to include a facility to white-list and black-list through crab.cfg commands – ostensibly in order to allow them to test sites[8] (See Appendix A, exhibit A) or if sites had problems specific to CMS[xiv]. Using these commands however users could exclude particular areas of the grid, or force their jobs to run on particular computers within the grid just as the maintainer might – though "in principle users should not [use] white-listing or black-listing since [they] should assume the grid infrastructure is a failure-less infrastructure" (P14).

How to use this facility was widely shared among the community as it enabled CMS-Physicists to use the grid easily in a non-grid way[xv]. Physicists were under considerable

[8] A site is a collection of servers in the same computer centre with the same characteristics.

pressure to do physics analysis as quickly as possible in competition with other experiments and for publication deadlines. Using black-listing allowed them to avoid sites which slowed them down “the user can decide to create the job but skip directly this site, because I know if the job is submitted there I have to wait some days” (P15). Using white-listing, jobs could be sent directly to machines they knew well and that were known to work well often saving considerable time: “If I know that the data-set is on this site, ‘my-site’, and I want only to submit there I can force CRAB and the grid to create and submit the job only using this site" (P15). This circumvented the grid as allocator of jobs and used the grid resources as though they were an old-style computing cluster.

Further GGUS was circumvented as white-listing meant physicists would know where on the grid their jobs had run – and could telephone LCG staff at that site directly – “if there is a site-manager that is helpful/available there and I want to submit directly to this site I can do it” (P15).

As a CMS-Physicist involved in CRAB development explained:

> *“So what happens in reality. And this is something we clearly see with the coming of real data [from CMS and the LHC]. The user needs to go to a conference and so needs to do some activity like producing results, which should go in a paper, and publication and so on. So they need to access some data and they know, well they don't know but the CRAB points them to a couple of sites, say three sites. At some point the user sees in real life, that a bunch of jobs continuously fails in a site. From the user point of view they don't care if the jobs are failing due to the fact that the site is failing due [being] mis-configured, or for other kind of reasons like overload of the site, or problem with data-storage which is broken. So jobs are failing. So the user wants a way to say that my*

jobs should not go to that site since [the site] is preventing me to produce the results I need to do. If I can black list this site I know I can produce my results quicker" (P14)

One physicist recounted that using white-lists and black-lists meant dealing with a problematic zero-code was easy; "in that case I quite often try and send the job somewhere else, not use that particular grid site" (P2). Indeed some physicists believed that specifying sites using white-lists was the only way to use the grid effectively[xvi], or even was the correct use of LCG: as one stated when asked how they used the LCG "I use a tool called CRAB, which is a CMS tool which allows you to sort of specify places. You can specify places for it not to go to or places that it should go to. So I can try sending it somewhere else… you find out where the data is and then you tell the thing to send there" (P3)[xvii].

Such practices were shared through discussion and on websites which outlined the practices for others physicists (see Appendix A). Indeed those software specialists involved in developing CRAB acknowledged that "If I am a user I would use these kinds of things" (P14) despite knowing that the practice negatively impacts the grid as a whole.

The impact of White-listing and Black-listing on LCG

From a LCG-Gridpeople's perspective white-listing and black-listing through CRAB created significant problems. It made it difficult to test improvements in the grid (as physicists employed CRAB to flee from broken sites to successful sites it was difficult to get the volume of jobs needed to test and fix defective or problematic sites), monitor usage patterns[xviii] or monitor failures[xix]. These problems created a vicious circle[xx] as LCG-Gridpeople were then less able to improve the WMS and it also became increasingly ineffective. They were unable to resist CRAB's use in the practices of running CMS jobs on the grid[xxi]. They also had limited means of communicating with CMS developers – relying on experiment representatives within LCG.

CMS went further in circumventing the Grid WMS. They developed monitoring systems "that report independently the situation of the infrastructure as they see it, not as the [LCG-Gridpeople] see it" (P4)[xxii] which fed into CRAB, and thus reported to users on grid-sites' effectiveness.

ANALYSIS

The aim of this paper was to problematise the communities involved in the implementation of a grid and in so doing reveal the sociomaterial relationship inherent within this process. Using Pickering's MoP, the paper now analyses the case study from the perspective of the 'users' of the LCG – a community of experimental particle physicists with the shared intention of using LCG to undertake analysis in order that CMS ultimately discover "new physics".

This community's work practices, through which they sought to bring about their intentions, were always sociomaterial (Orlikowski 2007) with materiality constitutive of work (Barad 2007; Latour 2005) involving the grid, software, CMS (with its magnets[9], trackers[10] and calorimeters[11]) but also mundane technology such as laptops, videoconferencing systems, printers, email, desks, pens and pocket-calculators. The work was seldom repetitive or

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[9] Required to impose a magnetic field on the CMS.

[10] Required to produce data about the paths of charged particles through the magnetic field and measure charge and momentum.

[11] The central detecting components of CMS which measure energies from particles as they pass through the device (http://calor.pg.infn.it/calor2002/abstract/Presentation/introductory/Fournier.pdf)

precisely defined (Traweek 1988) through it included some routine practices such as running analysis jobs. These analysis work practices were however constructed from a process of "modelling" (Pickering 1995) in which they imagined their analysis activity, and the steps to undertake this activity, drawing upon a disciplinary agency of particle physics computing, in particular supercomputing such as using cluster-computing. When discussing the grid most CMS-physicists talked about "sites", "my-site"(P15), "machines" and the grid as a larger "cluster computer" rather than as a new form of architecture. This modelling was instantiated within their routine practices of analysis – they found it disconcerting that they could not access sites or know where their jobs would run on the grid. Indeed many knew their own university's data-centre well and continued to use older cluster computers for smaller analysis jobs before turning to the grid.

CMS-Physicists' routine practices of physics analysis were dynamic creative enterprises in the face of material resistance –through which they harnessed, tuned and innovated their sociomaterial work. Physicists were constantly tuning their analysis software and scripts. Faced with material agency from their technology they harnessed other technology and created new software to domesticate this material agency and mangle it within their work practice, then sharing such accommodations with others.

Resistances were faced from the grid as jobs were submitted but failed to return, or were returned marked successful (with a zero-code) but did not include results. Scripts, test analysis, debugging scripts, dummy jobs, even monitoring systems were created and experimented with in an attempt to understand problems. But errors could not be easily replicated or understood (Abbas 2004) and thus could not be easily tuned. The grid's material agency was performative (Barad 2007; Pickering 1995) and for particle physicists such material agency was an inherent part of their work. Just as the grid resisted, so the CMS experiment as a whole resisted – they were always pushing the boundary of the materially possible (Britton et al. 2004). For them technology was not an enabler of this work (and thus to describe them as 'Users' appears inexact), rather technology was inherent to their work and their work was constantly punctuated by material-resistance[12] which "emerge[d] by means of an inherently impure dynamic" (Pickering 1993) from the material-agency of the machines/technology assemblage of that work. Responding to this material resistance was not unusual or special – it was the diffused enactment of doing their job and was neither overtly political nor distractive. Their responses were not conscious acts of resistance, innovation or rebellion against the implemented technology (as "user-resistance" literature suggests (Kim and Kankanhalli 2009; Lapointe and Rivard 2005)) but rather the doing of work which was always sociomaterial (Orlikowski 2007) and thus always involved material resistances and mangled material and human agency (Pickering 1995).

For this community new technology was not a "stranger" (as Ciborra (1999) has described it) that must be made sense of: it was a constant unfolding part of their work practices and learning. The introduction of the LCG was not an important or significant occasion creating worry or concern; it simply added another material-resistance within their work practices. It was another thing to be experimented with, learnt, explored and potentially domesticated within their collective work practices.

In domesticating the grid the some CMS-Physicists learnt its affordances – the actionable properties of this inflexible architecture which "called out" to them (Hutchby 2001). This subset of CMS-Physicists experimented with these, discussed requirements with others, and in particular explored the opportunity to kill jobs, and then to exploit the white-listing and

[12] The term material-resistance is adopted here to differentiate it from user-resistance which will also be discussed. Material-resistance is the material-agency which inhibits the human agency towards achieving an intention. It draws, ultimately, from material agency of the world which it tries to tame (see Pickering 2005 p7).

black-listing facility of the grid middleware for their own ends. Through domesticating these affordances within CRAB they circumvented the material agency of the grid Workload Manager (with its aim to balance work across the grid) providing CRAB with its own material agency over the grid which allowed users to collectively direct jobs to sites. Others among the CMS-Physicists were however less interested and less technically capable of domesticating the grid – instead blaming CRAB for grid failures, and having to rely upon GGUS for support. Yet through the community's ongoing social interactions, learning and sharing of crab.cfg scripts, the domestication of the grid using white-listing and black-listing was slowly shared with the wider community. Ultimately then CMS analysis became very similar to their modelling of cluster computing – the physicists edited their crab.cfg files to select the "computer-cluster" of the grid to use. They then enrolled the "white-list" command to send the job to that site. If problems occurred they telephoned the white-listed site for support. For the community the grid now included "sites" and the directing of jobs to "locations".

This suggests that affordances of the grid were not fixed physical properties as is usually assumed (Gibson 1979). While the grid did indeed manifest probabilistic purposes (affordances such as running jobs) through physicists' experimentation and development of CRAB, the detailed materiality of the grid became appropriated and tuned to reflect their intentions and models. A minor hidden affordance (to white-list) intended for technicians and hidden away from view became an obvious affordance for users. Members of CMS explored the grid's fabric and the actionable properties of the grid were themselves "tuned".

This mangling led GGUS to constrain their actions since GGUS focused on supporting a global grid rather than clusters consisting of sites and locations. This in turn led physicists to further harness CRAB to ensure they could seek local support. While in general "we tend to take objects in the way they already show themselves in the world in which they are encountered as this or that particular thing – within an already implicitly existing relational whole" (Introna 2011) for this community everything was open to being learnt, redeveloped and redesigned. In the words of one interviewee within this community "if there is some of the official grid technology which isn't working then we would just bypass that and replace it with a home-grown replacement..." (P3) – in response to resistance from the grid, CRAB was harnessed for such ends.

The CMS case of tuning the grid was not unique. The physicists of the ATLAS experiment at CERN (a competitor to CMS) had similarly developed software which mangled the grid to reflect their intentions – though using a very different material artefact. In contrast to CMS-users' use of black-list and white-list through CRAB, ATLAS developed a centralised server which created sets of "pilot jobs" which were submitted to run on all computers on the grid. These jobs did not undertake analysis for ATLAS users but instead sat on each computer in the grid informing the server of the processing resources available. The ATLAS server would then pass ATLAS users' jobs to these pilot-jobs to run on machines which the server deemed had sufficient resources - so "reflecting the job-running priorities of ATLAS" (P11). This was "much better for the experiments, because once you get a job running in one place and you know the environment is good for your job, you just sit there on that machine forever, just bringing in more and more jobs" (P13). These pilot jobs act as ATLAS' own Workload Manager and wholly circumvented the grid's Workload Manager. As a systems administrator explained each experiment was "their own fiefdom" (P10) achieving a strong control over what was done.

Through these means (CMS using CRAB, ATLAS using pilot jobs) the grid as an inflexible distributed architecture was changed – the automatic allocation of jobs to sites was circumvented and became something users managed themselves.

But there is another community of 'users' of the grid: introducing the Maintainer.

The case study describes the actions of users from CMS and to a limited extent ATLAS. There was, however, another community engaged with the grid and attempting to mangle the grid to reflect their own intentions – the LCG-Gridpeople. Within the literature on implementation there is little consideration of those developing and maintaining the implemented system, and of the impact of users' improvisations and adaptations on this community. The term "user" is in widespread use but, lacking a similar term for this other community, this paper proposes the term "maintainer", defined as the disparate community brought together with the shared intention of providing a distributed infrastructure for all users. This contributes to Leonardi's call for research which crosses the artificial "implementation line" (Leonardi 2009) between 'development' and 'use'. This "implementation line" leads most studies to consider technology as broadly stable at the time of use, with development ceasing (Leonardi 2009). Yet for all but the most simple information systems maintainers are always undertaking "development" in their work – from installing operating system patches to software development , rewriting scripts and installing new components.

Maintainers were, within the case study, also "users" of the grid. For them the grid afforded monitoring, adjusting and developing. With 100,000 computers within the grid, problems such as hardware failures, operating system bugs, upgrade management and even undiscovered bugs in hard-disk firmware were faced (Zheng et al. 2011). Like the physicists they were constantly mangling the grid conceptually (redefining their practices towards the grid) and physically (re-writing the middleware and building tools including job submission software[13]) with the aim of achieving their intentional goals based on a model of grid

[13] See ganga.web.cern.ch/ganga for an example of such a system.

computing as transparent, seamless and dynamic (Smarr 2004). Maintainers were involved in the social and material construction of implementation alongside other "users". We now consider how the two communities tuning of the grid created a ground for negotiation and control between them. In this way the study provides empirical evidence of an alternative sociomaterial conception of the relationship between maintainer and user – as a Duel[14].

The duel between maintainer and user

The Users' community responded to the grid's material agency by a subset harnessing material agency at a micro-level (undertaking changes to CRAB) and sharing such changes with others who then added one or two lines within their crab.cfg file (e.g "ce_white_list=server.cern.ch") to exploit this accommodation. These collective actions significantly altered the work practices of maintainers. As workload management became increasingly controlled by users they found it hard to test and understand the allocation of jobs to the grid. They became focused on local issues (similar to cluster computing) and GGUS became problematic.

The negotiation for control over the allocation of jobs (workload management) was undertaken through users and maintainers harnessing of material agency which emerged temporally through their practices as a dialectic process of resistance and accommodation (Orlikowski 2007; Pickering 1993; Pickering 1995). Ultimately maintainers were unable to respond to the mangling of white-listing into physicists' work practices and into workload management (or indeed ATLAS' adoption of pilot jobs).

Within this negotiation for control, the maintainer's options were limited. The option of using social agency and appealing to CMS physicists to change their ways would likely have been

[14] Duel is here defined as "Any contest between two persons or parties." - Oxford English Dictionary

unsuccessful – they were doing what they were supposed to do in pursuing “new physics” quickly. Maintainers might have marshalled their material agency over the grid middleware itself (rewriting it to preclude white-listing), but this would have made their own work practices extremely difficult; would have been a huge undertaking and would be opposed by CERN as a waste of effort.

Maintainers work practices had been shaped by the actions of users harnessing of material agency –an example of what Jones has termed “double-mangling” (Jones 1998). Lacking the power or domination over workload management and analysis work practice (either through social or material agency) they ultimately responded by changing their intentions – so scaling back their desire to create a seamless grid and accepting experiments control over workload allocation. In this way the architecture of the grid was changed – for CMS-Physicists it was now a “cluster of clusters”. Maintainers only long term plan was to improve the grid’s WMS such that white-listing and black-listing would prove inefficient and CMS-Physicists might harness the improved workload manager so returning the Grid to its intended form. If maintainers failed to achieve this improvement though “the impact ultimately … [would be] that the workload management system would be scrapped, because it would be investment in something useless” (P6) – an act of abandonment of the intention of a grid as “transparent, seamless and dynamic” (Chetty and Buyya 2002; Smarr 2004) and a permanent change to the architecture of the LCG towards cluster computing. While maintainers aimed to control the grid architecture they proved unable to do so in the face of CRAB and the collective learning of CMS-physicists . As one interviewee stated the relationship between the experiments and LCG is “Predator vs. pray” (P11).

DISCUSSION OF THE IMPLICATIONS OF THIS CASE

This case study contributes to our understanding of users' sociomaterial practices when facing an implemented grid. Existing studies have demonstrated users harnessing material agency in response to a new system, for example by removing mouse-balls (Ferneley and Sobreperez 2006), sabotaging data entry (Marakas and Hornik 1996) or by improvising the use of free-text fields in data entry (Orlikowski) or working on improvements (Leonardi 2011). This study contributes by providing an example where users harnessed material agency, and collectively shared this harnessing among their community, to emergently control the fundamental architecture of the inflexible grid being implemented and to shape it towards their intentions. This was not an organised rebellion but rather an emergent sociomaterial accommodation which as an unintended consequence re-architected the grid to the detriment of another community's intentions. This suggests that "user-resistance" towards an implementation (Hirschheim and Newman 1988; Kim and Kankanhalli 2009; Lapointe and Rivard 2005), which is defined as a human-agency (Hirschheim and Newman 1988) acted by human towards the machine or social structure, might be redefined to include a dialectical sociomaterial resistance (a dance between human and material) in which a range of communities are engaged.

By conceptualising all communities involved in an implementation as "users" and seeking out their intentions and their agency over the implemented technology this paper conceptualises user-resistance as a ***duel of material agency*** in which communities (including a range of users and maintainers) each enrol material agency to accommodate the resistances a new information system presents to their work practices, in an ongoing unfolding dance with the other communities various accommodations, and the further resistances such accommodations cause. That these material accommodations interact with those of others is not intentional but is a material influence on future practice – a change in the shared technology which can lead to further resistances for other communities.

The study shows that resistance cannot be assumed to be an "opposition of a user to change associated with a new [information system] implementation" (Kim and Kankanhalli 2009) because, in this case, users were not "opposed" to the grid or opinionated towards it. Rather it is the **intentionality** of the various communities that is important; here user-resistance is seen as a rationalistic response to a friction in the smooth running of the sociomaterial performance of work based on their intentions, friction which may or may not be useful depending upon the intentionality of those users. Just as with mechanical-resistance in engineering, such resistance can be both welcome, and unwelcome (friction is welcome to hold nuts and bolts together – until they must be removed) and this friction is finely balanced and tuned.

The paper argues that in response to this friction communities can enrol either social or material agency. In the case of social agency this manifests in power (Doolin 2004; Walsham 1993), recalcitrance (Marakas and Hornik 1996) or similar social responses. Communities exploiting material agency in user-resistance are less researched. However seen in this way resistances such as the removal of mouse-balls to stop an information system operating (Ferneley and Sobreperez 2006) can perhaps be viewed as based on intentionality of idleness and an enrolment of material agency of the mouse and mouse-ball which might be the only material agency such users were able to control. Including the maintainers within such an analysis might also prove interesting; what material agency might they bring to bear? Superglue to stop the balls being removed perhaps?

The MoP provides a useful theoretical framework for researching implementation crossing the "implementation line" (Leonardi 2009) by focusing on a temporally emergent dialectic of resistance and accommodation as individual practices are shifted by the newly implemented technology, and as they materially react. By introducing a theory of learning communities, (itself drawn from practice theory and focused on shared intention), this paper looks beyond individual accommodations and explores how these become shared among wider communities through communication. In this way the paper responds to Pinch's (1999) criticism of the MoP as individualistic and provides a means of seeing resistance and accommodation as a collective pursuit by communities with shared intention. This allows the MoP to consider social collectives, themselves tied by intentions, and so provides research of implementation with a means of understanding resistance both individually and collectively for both "users" and developers/maintainers.

Defining the duel of material agency acknowledges Jones (1998) notion of a "double-mangling" whereby "both material and social agency are mutually and emergently transformed" (Jones 1998, p297) extending this to discuss, not just the exploitation of mangling to transform social practice, but an ongoing tension within the mangle of practice – a duel for control played out emergently through the mangling of relevant human actors and the material properties of a system which is shared by a range of communities, with respect to their differing intentions for the same material resource.

Finally the paper demonstrates the benefits of detailed analysis of technology (in this case configuration files, log files, analysis job submission) within qualitative studies in information systems. Without engaging with the complexity of operating the LCG this study would not have been possible.

CONCLUSIONS

This paper asked how do communities come to control a grid during its implementation? Using a case study of the implementation of a grid for the Large Hadron Collider, and a theoretical framework based on sociomateriality, the paper demonstrated that for such large inflexible infrastructure the architecture of the grid can be negotiated through the materiality of the grid itself – a negotiation taking place between users and maintainers (a term the paper introduces) without direct social interaction. The implemented grid is negotiated and contested as users and maintainers harness material agency and share their accommodations within their communities and, despite its inflexible nature, the grid is fundamentally altered by this negotiation. The paper demonstrates the importance of intentionality within sociomaterial understandings of practice, and the importance of realising that an implemented technology is shared between multiple communities of different intentions such that negotiation is required.

This has important and timely implications for grid and cloud computing as they become increasingly used. This study suggests that services such as Amazon's AWS Infrastructure as a Service[15] might be materially altered by users harnessing their material agency and sharing such accommodations. Indeed one might argue that distributed denial of service (DDoS) attacks faced by AWS [16] (in which users harness a large number of computers to flood the service with competing requests[17]), are an example of users harnessing material agency in just such a way albeit with an unlawful intentionality. Maintainers at Amazon have limited means of response other than harnessing material agency themselves in a duel for control of the cloud.

[15] http://aws.amazon.com/ the provision of an elastic computing facility for virtualised computers.

[16] http://www.pcworld.com/businesscenter/article/185458/ddos_attack_on_dns_hits_amazon_and_others_briefly.html

[17] http://en.wikipedia.org/wiki/Denial-of-service_attack

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APPENDIX A

Exhibit A: CMS' online Frequently Asked Questions (FAQs) detailing CRAB.cfg options (truncated). Note CE stands for Computing Element – a computer-processor on the grid. SE stands for Storage Element – a data-storage device (e.g. Hard disk/Tape Drive) on the grid.

If you want/need to select/deselect some site, you can use: (see Crab FAQ for more info)

- Ce_black_list – (refuse access to all the listed CEs, allow all others)
- Ce_white_list – (allow access only to those CEs listed)
- Se_black_list – (remove the selected SE from the list of sites hosting data)
- Se_white_list – (select only the SEs listed)

CE Black List: all the CE whose name contains the following strings (comma

separated list) will not be considered for submission.

So, in summary, if you want to force your jobs to go a specific site (eg if you want to test the site), use "SE_w/b_list". If instead you want to access some dataset but you want to avoid a site (because you don't trust it), use "CE_w/b_list". In addition, se_w/b_list cannot be used with None as input dataset.

Exhibit B: A Wiki page showing CMS-Physicists how to simulate a CMS Higgs-Boson discovery using simulated data. Within this script it directs the user to se_white_list for no apparent reason.

Create the CRAB configuration file: Demo/MyTrackAnalyser/test/crab.cfg and give it the following contents, replacing the items in brackets <…> appropriately:

```
…
[EDG]
se_white_list   = <location found with dataset discover page (e.g., srm.unl.edu)>
…
```

Exhibit C: This public wiki (https://wiki.hep.wisc.edu/cmsops/CRAB (accessed July 2010 and truncated)) provides a guide to using CRAB for High Energy Physicists at the University of Wisconsin and includes a list of sites for White-Listing to USA resources only.

Use DBS Data Discovery to figure out the location of data you want. A list of sites is kept too.

In your crab.cfg you must have matching se_white_list with ce_white list for US submittion, and use scheduler = condor_g

Site	Storage Elements se_white_list	Compute Elements ce_white_list
CalTech	cit-se.ultralight.org	cit-gatekeeper.ultralight.org
Florida	srm.ihepa.ufl.edu	pg.ihepa.ufl.edu hg.ihepa.ufl.edu iogw1.hpc.ufl.edu
MIT	se01.cmsaf.mit.edu	ce01.cmsaf.mit.edu
Nebraska	srm.unl.edu	red.unl.edu
Purdue	dcache.rcac.purdue.edu	lepton.rcac.purdue.edu osg.rcac.purdue.edu
SanDiego	t2data2.t2.ucsd.edu	osg-gw-2.t2.ucsd.edu osg-gw-4.t2.ucsd.edu
Wisc	cmssrm.hep.wisc.edu	cmsgrid01.hep.wisc.edu cmsgrid02.hep.wisc.edu
Brazil (UERJ)	se-dcache.hepgrid.uerj.br	osgce.hepgrid.uerj.br

Non-US Tier-2 sites do not use condor_g! These are part of the LCG. This is not an extensive list, see list of sites .

Site	Storage Elements se_white_list	Compute Elements ce_white_list
Bejing	srm.ihep.ac.cn	lcg002.ihep.ac.cn
Estonia	io.hep.kbfi.ee	oberon.hep.kbfi.ee
Hungary	grid143.kfki.hu	grid109.kfki.hu
Korea(KNU)	cluster142.knu.ac.kr	cluster50.knu.ac.kr
Tiawan	f-dpm001.grid.sinica.edu.tw	f-ce01.grid.sinica.edu.tw

ENDNOTES

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[i] LCG is "just a processing machine that sits there and nobody really has to know how it works"(P1).

"People want enough disk space, they want fast CPUs that they can run their usually very inefficient programmes on, and they want it twenty four seven, and also during Christmas" (P2).

[ii] "The job of the CMS software … is to select and process detected events [particle interactions], deliver the processed results to experimenters within the CMS collaboration, and provide tools for them to analyze the processed information in order to produce physics results" (Heavey et al. 2006)

[iii] "We don't want it that all the physicists need to know all the details of the Grid and also about the CMS infrastructure. We wanted a tool that provides all the information to run the analysis directly on their data [like] their local machine" (P15)

[iv] "the development of CRAB since the beginning is driven by feedback coming users, so there is a developer and user in free contact, and there are forums and mailing lists where we exchange… what was the most important things to address" (p14)

[v] "we provide tutorials for the user. We give them two or three tutorials each year... with big groups of physicsts...we also provide fliers, material in the TWIKI , and the CMS workbook" (P15)

[vi] "the way people learn how to use the Grid is by getting a working [CRAB] script from someone… and starting from there and trying to run it and trying to modify is to suite their needs" (P2)

[vii] e.g. https://twiki.cern.ch/twiki/bin/view/Main/CRAB

[viii] As one Maintainer stated " [we] have a Workload Manager which is able to do resubmission automatically on behalf of the user in case the site where the job was sent is not behaving correctly. Or we have the possibility in the [LCG Control system] ... to ban explicitly given sites, so there are white listsviii and black listsviii. So [a central Grid administrator] can black-list a site, [and they] can white list another site, if [they] want. So that basically the workload management system is forced to consider all and only the sites left that the application wants to be used"(P4).

[ix] "What frustrates users is that they follow the instructions, submit the job which sometimes works and sometimes it doesn't. But due to stupid things somewhere the job fails" (Minutes of a LCG sub-group collaboration meeting).

[x] Support infrastructure was also often very slow because of a rush to get the Grid running "we were pushed to rush it out before it was really ready, so we then had a lot of difficulty trying to support the bad code"(P12)

[xi] "When things aren't being [allocated] they say the program is crap, even though it is not the actual program where things are going wrong, it is usually one of the different grid components, not the programme" (P12).

[xii] "You cannot do so much - you have to try to improve as much as possible the logging [GRID failure data] so the support [GGUS] can help the user quickly to understand what is going on. But for the end user who is at the beginning of their experiences is not going to understand what is going on when there is a problem" (P14)

[xiii] Users could kill jobs "not only because it is longer but also because the user decides that there is a mistake and they to kill a job" (P15)

[xiv] Of Black-listing and White-listing: "it was a requirement from the user … It was a functionality required directly from the user because at sometime could happen that a remote site has special problems that are not really Grid problems but could be some problem with the installation of the remote site" (P15)

[xv] "I see that the way we use [LCG] may cause other people headaches. But it is simply because otherwise you get into this really boring alternative which is you submit it without specifying where to go. And then it comes back from one place and says it doesn't work. So you say – OK, ignore that place, try somewhere else. You know you are gonna make it work, but you shortcut that by finding out… so this one thing of knowing where you data is, if you can find that out independently it releases more time to make it happen" (P3).

[xvi] "user at some point started thinking, at some point, starting feeling that some sites are better than others, and so the only way to take the opportunity to use what they feel is working better is to use white-listing and blacklisting." (P14)

[xvii] "I can send a job directly without using the grid. So I guess half the time I probably do that, in the end"

[xviii] "some parts [of the Grid] are very much more used than others" (P9)

[xix] “The experiments (well, the one I work on, CMS, at least) continue to find new and novel ways to abuse the computing systems, and [LCG-GridPeople] have to respond to those.” (Blog Entry on GridCast - http://gridtalk-project.blogspot.com/2010/07/welcome-to-wlcg-london.html)

[xx] LCG-GridPeople’s role is to observe the usage of the Grid through a variety of monitoring and dashboard applications and ensure that the computing elements and storage elements their site contributes to the Grid are running effectively and have the correct software infrastructure installed. They are formally evaluated on the availability of the SEs and CEs they administer. This is no easy task, particularly as in preparation for the launch of the LHC many sites are installing large numbers of Grid components. Further each site’s computers and storage devices are likely to be shared by a range of experiments at the LHC, and indeed in other sciences. The Grid middleware is changing regularly and the powerful experiments regularly demand new software be installed on sites CEs. Such complexity means that the skills of LCG-Gridpeople are crucial to a site’s success, yet their skills vary; “the biggest problems today is managing such a big infrastructure where there are so many sites and not all the sites are managed with the same level of body of quality. At the same time the software which implements the servers is not mature enough in order to be easy to be managed (…) this requires a very experienced people in managing sites which is not always the case” (P4).

[xxi] “We are trying to find the best solution to each particular problem domain, integrate it into our release so everyone can use it. Now if there was a user sitting in isolation they would probably have to use what we provide, they don’t really have much choice. But these users don’t really exist so much, they all work for experiments with lots of influence and resources and everything. And which occasionally, possibly often, have very high influence in some of the sites as well, they can ask the sites to install various services. So they can bypass stuff. Bypassing is probably a pejorative phrase, it is just they choose to use an alternative route. (…) But certainly one of [LCG-Gridpeople’] big services is workload management. So the idea is that this takes all your jobs and manages them for you, submits them to the right place, so you send them there and forget about them until you all come back. But on your user interface you can implement most of this stuff, if you want to, to your own satisfaction. And we find people have done that.” (P6)

[xxii] "CMS developed its own catalogue of its data" (P15)