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Distributed Development and Scaled Agility: Improvising a Grid for Particle Physics

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Abstract

There has long been a debate in system development centered around the dichotomy between control and innovation, exemplified in recent years by the movement for agile methods. This paper seeks to bring some theoretical underpinning to this discourse by drawing upon the literature of organizational improvisation. We relate this discussion to an example of a large scale, distributed system development effort undertaken "in the wild" - the ongoing construction of a particle physics Grid in the UK, itself part of the world's largest grid. The investigation of the improvisation-paradoxes in the project reveals a new vision of *Scaled Agility*. This reflects the encompassing adoption of an improvisational approach, drawing upon the traditions of organizing physics experiments and their discursive and reflective practices. Agility on such a scale inevitably brings with it paradoxical tensions, yet here they provide the energy to hold together a distributed community developing a distributed system.

Key words: agile system development, improvisation, Grid computing, particle physics.

1. Introduction

The technical, organizational and cultural contexts within which information systems development work takes place have multiplied and diversified in the last decade, extending well beyond traditional high-reliability software engineering to areas such as web development, games programming, distributed infrastructure deployment and package configuration. These diverse efforts are now located within equally varied business models including open source, outsourcing, and global sourcing (Willcocks and Lacity, 2006). One result is that much systems development activity has become re-scaled as a virtualized effort undertaken by loosely coupled alliances and collectives, distributed in time and space. This paper draws upon one such case, the development of the UK particle physics computing Grid – GridPP, and seeks thereby to question both the established paradigms of system development as a planned and controlled activity, as well as the conventional account of agility.

GridPP provides an interesting case of distributed systems development. It is part of an initiative which aims to produce not just a working system but a new generation of computing technology that will potentially have significant impact on scientific research, and may foreshadow the "next generation Internet" (Abbas, 2004, Carr, 2005). The Grid is being developed as a large scale distributed collaboration, rather than by a few innovative centers or companies; collaborative and distributed working are predominant characteristics of this effort. Thirdly, it is being done by particle physicists who come from a community with very distinctive work practices and culture (Traweek, 1988, Knorr-Cetina, 1999) and have a record of success in developing innovative computing solutions of which the World Wide Web is the most notable example (Berners-Lee, 1989). All this has a strong influence on their attitudes to technology and their system development practices. More recently particle physicists have become pioneers in global Grid development, working in collaboration to build the world's largest Grid ready for the launch of the Large Hadron Colider (LHC) at CERN in 2008.

Mobilizing to build this Grid is a grand systems development challenge in technical, organizational, political and human terms, and one that takes us well beyond the usual software-centric view of development activity, while the scale, complexity, need for innovation and diffuse resource base defy the plan-based approaches with which the mainstream literature of ISD has been preoccupied. The physics community, drawing on their laboratory culture and an experimental tradition that fuses developers and users, has approached this task through international collective structures with a shared commitment to doing 'new physics' rather than extensive formal lines of authority or legal obligations. In the Grid development work itself no explicit methodology is systematically employed apart from some *post hoc* rationalization and documentation to satisfy funding requirements.

This approach echoes the long standing observation from the field that methodology is not effectively or extensively used (Avgerou and Cornford, 1993, Bansler and Bodker, 1993, Dobing and Parsons, 2006), but often "faked" (Parnas and Clements, 1986) and used as a "fiction" to create some sense of coherence in day-to-day activities (Nandhakumar and Avison, 1999). Such observations have caused many to rethink the status of method and methodology in systems development. Ciborra (2002, , 1998), for example, speaks of the crisis generated by an overdose of method and planning and the ontological assumptions it draws on, and asks us in language that particle physicists might appreciate, to "suspend the belief that behind the messy everyday reality there is a geometric universe" (Ciborra, 2002) and substitute this with new concerns for care, hospitality and cultivation. Such challenges to the belief in method, and evidence from empirical studies of development work, have given rise to the idea of so-called "amethodical" development (Truex et al., 2000) that can better appreciate and support innovation and organizational change, adaptation and experimentation, as well as accidents and opportunism. If organizational landscapes are emergent or enacted (Weick, 2001, Weick, 1993b), as is equally technology (Orlikowski, 2000), so IS development practices need to support a strong contextual contingency, and allow for "improvisational action and bricolage" (Bansler and Havn, 2003). Still, as Truex et al (2000) suggest, amethodical practices, despite enduring for decades, are usually placed at the margins of the discourse of system development. However, the rise of agile methods and its associated conceptual apparatus have served to bring such ideas closer to the mainstream, though they may be better described as 'methodical-lite' rather than amethodical.

Agility means quickness, lightness, and nimbleness (Highsmith, 2002). Fowler and Highsmith's *Agile Manifesto* (2001) lays out four guiding values, stated as points of view, that privilege one perspective over another, and which quite directly critique the development orthodoxy of the 1980s and 90s:

- individuals and interactions over processes and tools;
- working software over comprehensive documentation;
- customer collaboration over contract negotiation;
- responding to change over following a plan;

We suggest, however, that agility is not just a case of substituting a new set of controlling ideas for an old set; the challenge is to blend a capacity for agile performance, innovation and surprises with a means and context that sustains the focus and momentum of a development effort (Williams and Cockburn, 2003). Some recent attention has been paid to organizational cultures which sustain agility (Adolph, 2006) but the concept of agility or agile processes for systems development has not been substantially studied as an organizational phenomenon or linked to organization theory. Drawing upon the organizational improvisation literature (Weick 1998, Cunha et al 2000) we here explore the complicated and at times contradictory ideas underlying agility as paradoxes, for example, learning to "plan not to plan" (Baskerville, 2006) or to achieve a "disciplined messiness" (Highsmith, 2002). In this we recognize that serious consideration of agility calls for a rejection of any bi-polar distinctions between concepts like planning and serendipity (Baskerville, 2006), discipline and creativity; and that embracing such paradoxes is the way forward. We do this through the ideas of organizational improvisation (Weick, 1998, Cunha et al., 1999), drawing out paradoxes we identify within such literature. This is a literature that does not seek to deny or negate the value of concepts of structure, design or order; rather it suggests that it is in the tension and interaction between these and their opposites: structure and change, order and chaos, control and freedom, that creative attitudes, innovative outcomes, and productive practices may be found.

The tradition of using paradox as a dialectical device to examine complex situations, and to build theory, in well established within organization science and IS (e.g. Poole and van-de-Ven, 1989, Chae and Poole, 2005, Boland, 1987). Paradox, as used here is not to express the illogical, impossible, or un-resolved, but rather to help reveal the fundamental source of collective action distributed in time and space. Poole and van de Ven (1989) identify paradoxes as "tensions and oppositions between well-founded, well-reasoned, and well-supported alternative explanations of the same phenomenon". They go on to suggest that "when juxtaposed they present a puzzle for the theorist, because each side seems valid, yet they are in some sense incompatible or hard to reconcile". Our approach is similar except that we are not primarily or exclusively interested in theory building, but in how people in a systems development setting live with and exploit paradoxes. Paradox provides a means of presenting the tensions, dynamics, motivating challenges, and pools of energy that can animate a system as a performance (that drive its enactment). In this way the focus on paradox provides the opportunity to rethink distributed and agile system development practices.

The rest of this paper is laid out as follows. Section 2 develops the conceptual basis which we use to analyze the empirical material. Section 3 introduces Grid technology and GridPP, and describes our research methodology. This is followed by the findings from the case study in section 4. Section 5 discusses and concludes the paper by revisiting agility and proposes the concept of Scaled Agility.

2. Conceptual Basis: Organizational Improvisation

Cunha *et al* (1999) define improvisation as "*the conception of action as it unfolds, by an organization and/or its members, drawing on available material, cognitive, affective and social resources*". This definition emphasizes two aspects. Firstly, the temporal order of improvisations, namely the convergence in time of conception and execution (Moorman and Miner, 1998), or "real-time planning" (Miner et al., 2001), though we should note Ciborra's (1999) phenomenological reading that shifts from a cognitive account of planning compressed against action, to one emphasizing subjectivity and recollection. Secondly, *bricolage* – the aspect of finding solutions from available rather than optimal resources – which is often implied or used interchangeably with improvisation (e.g. Weick, 1993b, Weick, 1993a, Ciborra, 2002), and which Cunha *et al* (1999) consider to be inseparable from the action of improvisation.

Improvisation is essentially a performative concept, and writings on organizational improvisation have often drawn heavily upon direct metaphors of performance, most notably jazz (Barrett, 1998, Hatch, 1999) and improvisational theatre (Crossan, 1998). From this we understand improvisation as a collective endeavor, one involving people together, both doing and observing, with their actions, thoughts and available resources in relationship one to another. Within the field of information systems, improvisation and *bricolage* have been used often to critique the dominant ontology of planning and control and the pervasive normative tendencies that follow (Elbanna, 2006, Ciborra, 1999, 2002, Ciborra et al., 2000, Lanzara, 1999, Orlikowski, 1996). As Ciborra (1999) argues, improvisation is important, even central, to understanding how effective information systems are built both as a routine and as rooting them to context, and potentially brings a "small Copernican revolution" to our understanding of the relationship of planning to action.

Inspired by the paradoxes of improvisation suggested by Mirvis (1998) and Ciborra's (1999) work, we present here a set of conceptual constructs, what we call improvisation-paradoxes, that draw upon and synthesize the literature on organizational improvisation. Table 1 lists these constructed paradoxes with examples of the conceptual repertoire they draw upon. These then serve as the conceptual vocabulary for the case study presented in the following section.

Pragmatic creativity: Improvisation does not happen at random. It is either a re-action to circumstantial (probably un-predicted) events, or a pro-action to obtain a future state via unknown paths. Visions which articulate a gap between reality and possibility can induce actions which are partly planned yet significantly emergent (Mintzberg and McHugh, 1985) and improvised (Crossan et al., 1996). Improvisation is situated and highly pragmatic – it gets things done

Improvisation-Paradox	Related theoretical constructs	Sources
Pragmatic Creativity	environmental turbulence task uncertainty unplanned-for occurrences task complexity drop your tools visions	(Moorman and Miner, 1998, Ciborra, 1996); (Dahlbom and Mathiassen, 1993) (Miner et al., 2001) (Hutchins, 1995, Weick and Roberts, 1993) (Weick, 1993a) (Hatch, 1999, Mintzberg and McHugh, 1985, Hutchins, 1991, Weick, 1993b)
Oriented Drifting	convergence of planning and execution mixing the pre-composed and the spontaneous magnetic fields minimal structure plan to improvise artful planning	(Moorman and Miner, 1998) (Weick, 1998) (Weick, 1993a) (Cunha et al., 1999) (Miner et al., 2001) (Baskerville, 2006)
Retrospective Order	retrospective sense-making *ex post* interpretation transient constructs & Persistent structure	(Weick, 1993b) (Lanzara, 1999) (Lanzara, 1999)
Managed Serendipity	organized anarchy collateral structure experimental culture the aesthetic of imperfection a sense of urgency.	(Cohen et al., 1972) (Cunha et al., 1999) (Cunha et al., 1999) (Weick, 1999) (Crossan, 1998, Hutchins, 1991, Mirvis, 1998)
Collective Individuality (Mirvis, 1998)	facilitative leadership trust and kinship emotional communication hanging out fluid communication.	(Crossan, 1998) (Crossan, 1998, Weick, 1993a) (Hatch, 1999) (Barrett, 1998) (Orlikowski, 1996, Miner et al., 2001)
Anxious Confidence (Mirvis, 1998)	Individual skills and creativity formative context organizational memory moods	(Hutchins, 1991, Moorman and Miner, 1998, Orlikowski, 1996) (Ciborra and Lanzara, 1994) (Moorman and Miner, 1998) (Ciborra, 2002)

Table 1. Paradoxes of organizational improvisation.

here and now – and we will choose to get the same thing done another way at another time or place. Factors that induce improvisation come from several sources; the most common is uncertainty, or environmental turbulence (Moorman and Miner, 1998). But unexpected and "unplanned-for" (Miner et al., 2001) occurrences or tasks can arise inside the collective too (Cunha et al., 1999), for example, if the complexity of a task is beyond the scope of rational planning, accumulated knowledge or predetermined method at a micro level. A case in point is Hutchins' (1991) description of navigation as collective improvisation when the crew of a ship whose power system failed brought it into harbor by 'working out' a set of routines among themselves while none of them had a high level view of how the complete system works.

Oriented drifting: Whether responsive or deliberate, improvisation is extemporaneous (literally out of time) and may appear incongruous and puzzling to others (see Weick's (1993a) firefighters at Mann Gulch). But improvisation is not random or uncontrollable. As either the "convergence of planning and execution" (Moorman and Miner, 1998), or the "subjective and highly circumstantial interpretation of the past" (Ciborra, 1999), it allows for powerful moments of direction as things are "worked at" to "fill the gaps between the artificial models and unfolding circumstances" (Ciborra, 1999). As Weick (1998) comments, "improvisation is a mixture of the pre-composed and the spontaneous". Cunha et al (1999) suggest "minimal structure" to express the controls desired to achieve improvisations that progress (Crossan, 1998, Orlikowski, 1996, Weick, 1998). Such controls, usually operating via culture or ideology (Weick, 1993b) rather than formal managerial channels, may include clearly articulated goals or a shared vision to provide a sense of direction and serve as a "magnetic field" (Weick, 1993b) which, without prescribing individual action, is normative in shaping such action.

Retrospective order: Retrospective sense-making (Weick, 1993a) can provide order, purpose, and coherence (Barrett, 1998) to improvised activities which may seem chaotic on the surface or at the time; "Whether treated as a noun or a verb, improvisation is guided activity whose guidance comes from elapsed patterns discovered retrospectively" (Weick, 1998). Similarly, Lanzara (1999) comments that meaning often arises from *ex post* interpretation and sense-making by a large number of dispersed agents, rather than from *ex ante* planning and implementation by a central designer. A project's milestones and deadlines may serve as devices for such retrospection (ibid.). Lanzara (1999) also offers the concepts of "transient constructs", such as "makeshift artifacts, recombinant routines, … ephemeral organizations, disposable symbols, fugitive meanings", used as a way to embody experience and what is known *so far*, working like "arches of a bridge thrown across time" to sustain some continuity and stability. Thus, at the macro-level, an unfolding improvisational performance and reflections on it, give rise to (or jointly enact) an "emergent order" (Miner et al., 2001), or "persistent structures" (Lanzara, 1999) which in turn can be drawn upon by others (Orlikowski, 2000).

Managed serendipity: We might imagine that certain organizational configurations enable and support improvisation. For example, "collateral structures" (Cunha et al, 1999) or "minimal structures" (Barrett, 1998) may help foster improvisation by relieving members from the impositions of constraining formal and prescribed practices, allowing a repertoire of improvisational ideas to emerge. An "experimental culture" (Cunha et al., 1999) (just what you may imagine experimental physicists have) may help to nurture individuality through features such as tolerance to error (e.g. Crossan, 1998, Barrett, 1998, Hatch, 1999), or what Weick (1999) calls an "aesthetic of imperfection". A strong pro-innovation culture (e.g. Miner et al., 2001, Mirvis, 1998, Weick, 1998); and a sense of urgency (e.g. Crossan, 1998, Hutchins, 1991, Mirvis, 1998) may also be needed. Moreover, Miner et al (2001) suggest that organizations can plan to improvise, routinize processes to stimulate improvisation, and routinize the observation of their own improvisational activities, all without the content of improvisation being specified in advance.

Collective individuality (Mirvis, 1998): Creativity and improvisation may be encouraged and supported, but individual freedom has invariably to be bound by a level of group cohesion in order to achieve any collective goal, especially when, as in systems development, task complexity is beyond the cognitive capacity of any individual (Hutchins, 1995, Weick and Roberts, 1993). As Weick (1998) puts it, "discussions of improvisation in groups are built on images of call and response, give and take, transitions, exchange, complementing, negotiating a shared sense of the beat, offering harmonic possibilities to someone else, preserving continuity of mood, and cross-fertilization". Facilitative leadership (Barrett, 1998, Crossan, 1998), trust (Crossan, 1998, Weick, 1993a), and fluid communication (Orlikowski, 1996, Miner et al., 2001) nurture such group performance. These characteristics express what Hatch (1999) refers to as a replacement of dependence on rationality with emotional communication, "as influence and persuasion replace authority as avenues for getting things done in de-layered organizations". Such emotional ties do not have to stem from self-disclosed intimacy but from shared actions, "hanging out" and a sense of membership in the collective (Barrett, 1998).

Anxious confidence (Mirvis, 1998): Emotional ties also serve to provide a "safety-net" for members of a collective to cope with anxiety, or to "deal with [the] affective element" in their performance (Cunha et al., 1999). As Ciborra (2002) points out, our moods change the way we encounter the world and make sense of situations. He considers improvisation as a mood and contrasts it with conventional moods of the development context such as panic or boredom, both of which fog vision and conceal possibilities for action. Mirvis (1998) suggests "anxious confidence" as the means to live with the ambiguity, complexity, and challenges of working in an improvisational collective. While Mirvis focuses mostly on individual capability and confidence, confidence is not only, even primarily, experienced through individual knowledge and skills (Hutchins, 1991, Moorman and Miner, 1998, Orlikowski, 1996) but also in organizational cultures and as "learned ways of thinking and behaving" (Moorman and Miner, 1998) which all can draw upon. Memory, practices and shared forms are requirements of improvisational success (Weick, 1998) as well as a will to depart from organizational traditions and norms (Cunha et al., 1999).

3. Research Context and Methodology

Grid computing is seen as new and different, and some claim it may "overturn strategic and operating assumptions… [and] pose daunting challenges for every user and vendor" (Carr, 2005). Foster et al (2001a) coined the term "Grid" as an analogy to the electricity grid, enabling access to networked high performance computing resources by just "plugging in" (Chetty and Buyya, 2002). While the term remains ill-defined and confusing (Gentzsch, 2002) a Grid is just a large number of distributed processors, data storage arrays and other devices linked through networks and presented to the user as though it were a single computer and without the need to address individual resources directly - similar to the way an operating systems hides the complexity of a PCs hardware resources from its users, but at another scale. In providing coordination of resource sharing on a global scale, Grids are most suitable for data-intensive and processing-intensive applications (Foster et al., 2001b) such as those in advanced sciences faced with "data deluges" (Colwell, 2003) from new experiments and procedures associated with "e-science" and "cyberinfrastructure" in fields such as medicine (mammography analysis), biology (genome databases), astronomy (massive sky surveys) and experimental particle physics (using particle accelerators) (Colwell, 2003, Hey and Trefethen, 2002). Among all these scientific areas experimental particle physics stands out because of the scale of their intended use of Grids, their significant contribution to Grid development, the fit of their style of analysis to Grids capabilities, and because of their necessity to distribute data and analysis tasks from large physical experiments.

Case Study: GridPP

In early 2008 the LHC particle accelerator at CERN, the European Laboratory for Particle Physics in Geneva, will begin to collide Hadron particles at energies close to those of the Big Bang in a search for the elusive 'Higgs-Boson' particle. These collisions will produce data for the LHC's four experiments (ATLAS, LHCb, ALICE and CMS). Since the Higgs-Boson is extremely rare - likened to searching for a person in a thousand world populations, or a needle in twenty million haystacks - the number of collisions and the subsequent data generated will be vast. The LHC envisages producing around 15 million gigabytes of data a year (a DVD every 15 seconds, or 1% of global information production (Economist, 2005)). To store and analyze this data the LHC requires the equivalent of 100,000 PCs working as a Grid by 2008 (Faulkner et al., 2006) so that physicists from around the globe can run huge analysis "jobs" on this data.

Building the LHC Computing Grid (the LCG) is a highly distributed, complex and poorly defined systems development task. Cutting edge hardware and software is used, new software standards are being negotiated, and middleware (a Grid's 'operating system') along with a wide range of supporting software is being developed in a range of programming languages, all in the context of a globally distributed collaboration. Within particle physics there is a long tradition of such large scale global collaborations from the 1950s (Traweek, 1988) and working on a distributed basis is well established (Knorr-Cetina, 1999). Funding for all this must be bid for from various national and multi-lateral funding agencies, which dictates that the Grid elements be globally distributed rather than co-located at CERN and proceed at different paces.

Activity for LCG is organized into projects, some of which extend beyond the physics community (for example LCG middleware is being jointly produced with EGEE, a wider European e-science project). The LCG itself has a hierarchically tiered technical architecture, with Tier-0 as the computer centre at CERN where the LHC data is acquired, initially processed and archived, and immediately distributed through dedicated 10Gb/s fiber-optic links to the Tier-1s consisting of national IT centers in each of the twelve major countries involved in the project. These Tier-1 centers interact with around 120 regional Tier-2 centers where analysis is undertaken, and with Tier-3 centers in individual institutions.

The UK contribution to LCG is GridPP, a collaboration of around 230 people based in 19 UK universities, the Rutherford Appleton Laboratory (RAL) in Oxford, and CERN. Work started in 2001 as two main activities: developing software to allow users to submit computing jobs to the LCG, and developing and operating the UK's component of LCG. For GridPP RAL is the UK's Tier 1 centre, with four Tier 2 centers: London, ScotGrid, NorthGrid and SouthGrid, each coordinating a number of institutes in their region.

GridPP's activity has been in three separate phases, each funded separately by the UK's particle physics funding establishment. The first (2001-2004 – titled "from web to grid") developed a test-bed prototype Grid across the UK. The second (2004-2006 – "from prototype to production") developed this prototype into a 'production' quality Grid with around 5000 processors, 0.65PB of storage and 1Gb/s data transfer rates (GridPP, 2006), while the third phase from March 2007 ("from production to exploitation") is preparing this Grid for analysis of LHC data, requiring an increase in scale by a factor 100 for storage, and a factor of 10 for CPU, and large strides in functionality, robustness, and usability (GridPP, 2007).

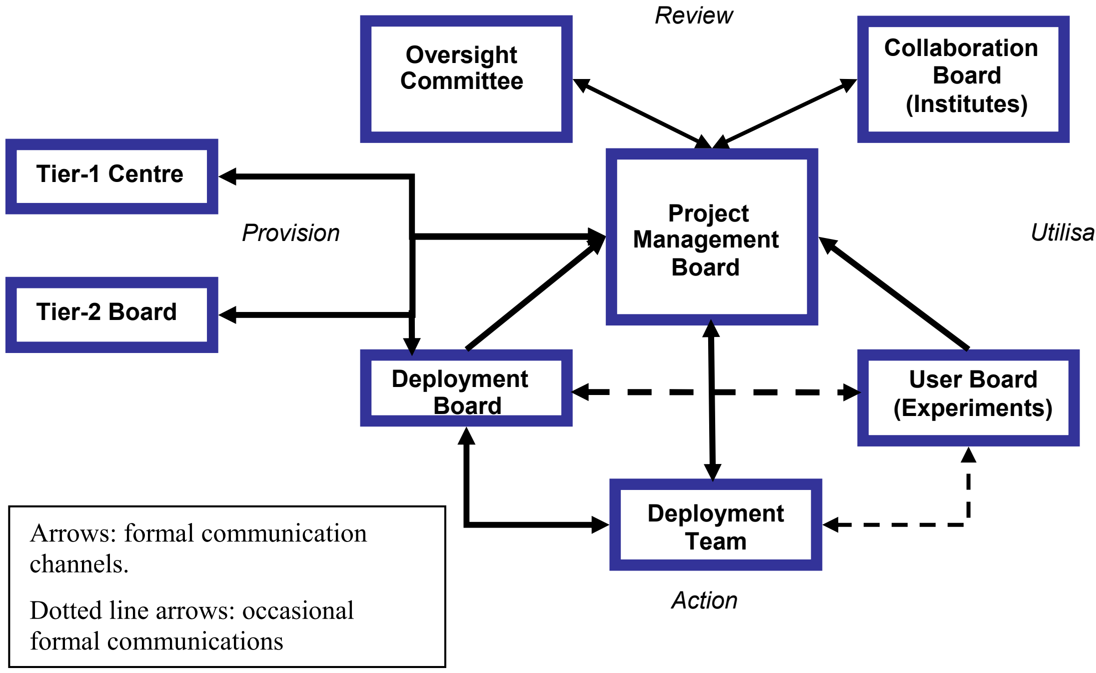

Figure 1: Organizational chart of GridPP (Adapted from the GridPP website)

GridPP's constitution is as a collaboration in which decisions have to be made on a democratic and consensual basis, and are implemented by influence and persuasion. The management structure in GridPP is best described as a network rather than a hierarchy (Figure 1). GridPP is a collaboration or collective, any attempt to describe it as an organization (with an organization chart) inevitably underplays its virtual, federated, overlapping and inter-connected nature. At its heart is the "Project Management Board" (PMB) coordinating the work. The PMB provides quarterly reports to the Collaboration Board representing the 19 participating institutes. These institutes enter the collaboration bound by a Memorandum of Understanding, which specifies the amount of resources and the level of service that each site is committed to provide, and the funding and support they will receive from GridPP in return. This serves more as a 'gentlemen's agreement' than a contract.

The PMB, in addition to three 'leaders' who chair and coordinate, consists of representatives from internal and external committees, boards and functions. Since GridPP overlaps with other projects and organizations the PMB includes representatives of the wider LCG project, the UK's e-science projects, funding bodies and the middleware producers (EGEE). The Deployment Board monitors resources deployment (which is undertaken by the Deployment Team), and the User Board represents the LHC experiments and physicists. Many people straddle multiple boards and key members of the project are constantly traveling between these boards' meetings. The 'practicing' particle physicists involved in GridPP are all members of one of the four experiments on the LHC and attend the associated meetings. Almost all the PMB, and around half of GridPP's members in general, have a particle physics background. Others are from computer science, engineering or other advanced sciences.

Most regular meetings of GridPP are conducted virtually. The PMB meets weekly through video-conferencing, producing weekly minutes of these meetings and setting out weekly action plans. The following day the Deployment Team meets to discuss technical issues. Meetings often draw upon wikis, webpages and blogs where GridPP communications are recorded. Mailing lists provide a constant exchange of questions and answers. These mailing lists also keep members aware of the ongoing activity, with PMB minutes posted to the main list and on the website. Knowledge of the project is located both in these shared resources but also in key individuals and carried around through their attendance in large numbers of meetings. In this balance between formal and informal communication, it is the informal communication which is considered crucial, particularly informal face-to-face meetings over coffee breaks and meals, or (being mainly a British male community) "in the pub".

The systems development activities undertaken by GridPP members are varied. Some focus on the installation and maintenance of Grid hardware; producing testing and management applications, ensuring patches are being installed, monitoring the Grids performance using various systems and managing workload and storage performance. Others program and configure middleware to support job submission, or liaise with other LCG developers on required changes. Others are involved in developing support infrastructure including producing Customer Relationship Management (CRM) type applications and responding to queries. Since GridPP is already in use, some members are 'users' writing software to undertake specific analysis tasks and submitting physics jobs, or simulated jobs, for the LHC experiments. Tension exists at times between these users and developers. Users want to run jobs quickly and effectively to progress their physics work, and who thus target their jobs at parts of the Grid which are known to be robust, whereas developers want these users to test newly installed parts of the Grid for robustness.

Methodology

The research presented here is an output from a research program conducting ethnographic informed research on GridPP's participants and activities as they develop and deploy the UK particle physics Grid for the LHC. GridPP's unique nature precludes comparative studies, but provides a revelatory case of distributed systems development practice. In approaching this study we have understood from the start that within particle physics it is intensive ongoing communication that shapes their work. As Knorr-Cetina (1999, p173) highlights: "Discourse runs through HEP experiments; it provides experiments with a massive spectacle of object features, of their story lines, and technical dramas, which are held by and spill from computer displays and printouts, transparencies, internal notes "documents", and together with all these, talk […] Discourse channels individual knowledge into the experiment, providing it with a sort of distributed cognition or stream of (collective) self-knowledge which flows from the astonishingly intricate webs of communication pathways". This highlights the need for research methods which capture the ongoing dramas and discourse of participants. Hence our choice of an ethnographic approach allowing direct observations by researchers embedded within the context over an extended time period (Czarniawska, 1997, Hammersley and Atkinson, 1995, Agar, 1996). The project team includes a senior experimental particle physicist to ensure that the research is not undermined by a lack of understanding of physics. Drawing from the interpretive research tradition in information systems the focus of this ethnography is on sensemaking and the symbolic world of those studied (Walsham, 1995).

Data collection began in August 2006, following earlier pilot work, and has included participant observations of weekly project management board meetings and deployment team meetings, quarterly GridPP collaboration meetings in the UK, international meetings of the LCG, site reviews carried out by GridPP, as well as observation of various forums and conferences in which GridPP participates. The research team has had full access to the GridPP main documentation. At the core of this research are 41 semi-structured qualitative interviews of between one and one and a half hours, undertaken at various universities across the UK and during two week-long periods at CERN in Geneva. Interviews were audio-recorded, transcribed and some then coded using Atlas.Ti software to derive themes and concepts. The Atlas.Ti coding and analysis was informed by the ideas of improvisation and agility discussed above. However, for the most part the analysis reported here is the result of the interactions among the project members and with other GriddPP people, rather than a narrow machine derived account. Finally the outline of the core ideas of this paper was presented to three key individuals on GridPP's PMB who broadly supported its findings. Table 2 provides details of the research activities undertaken.

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

Table 2. Details of research activities.

4. Research Findings

In a section above we outlined the GridPP project, the context, the structure, and the system being built. Here we describe the systems development activity itself, discussing its complexity, messiness and the means GridPP employ in coping.

From Experiments to systems development

The development and deployment of this Grid is driven by the imperative to analyze data from the LHC. As Grid technology is new and emerging rather than standardized or defined, GridPP cannot take a plan-based approach but must be exploratory and pragmatic with the aim to learn and improve by trial-and-error. Moreover, the complexity of the project means no one can have a clear overview of the whole system (Hutchins, 1991); requirements cannot be pre-specified in detail; architectures are conjectures, and even the one centrally designed piece of technology, the EGEE middleware, is modularized and released gradually.

GridPP faces many unplanned for occurrences and environmental turbulence in funding, human resources, external and internal technological changes, hardware and software configurations, user requirements from the experiments, computer market conditions, and other institutional and political factors. The response of those involved is not to plan, predict or formalize, but rather to respond pragmatically and creatively at the time, drawing on the down-to-earth and creative approaches embedded in particle physics tradition (Traweek, 1988). A member of the PMB explains, "*… we have somehow learned how to organize things, at project management level and how to get things, to take the pragmatic view and to, faced with a problem, how to get from here to the solution... not just in GridPP but in building hardware and building detectors... There's this background in problem solving and project management and the sort of pragmatic approach"*.

Yet such pragmatic creativity is undertaken alongside a strong (if minimal) project order, which orients it towards a clear and imminent project goal: the launch of the LHC, the data analysis it will require, the discovery of the Higgs-Boson it may enable, and ultimately Nobel Prizes. It is this belief in the LHC's launch, and belief in the Grid as a tangible achievable sub-goal, which drives the project forward. During our interviews this concept of a "shared goal" is frequently mentioned, and can be seen to bind efforts, solicit devotions, and bridge differences. For example, even though there is severe competition between experiments, they willingly work together in the Grid project because they need it to do 'new physics'. As commented by one interviewee, "*I said I was proud of being a particle physicist, this is 'cause particle physicists always get the job done; by and large because they are driven by one fundamental thing. They want their experiment to work when the beam gets into the accelerator, okay? And that transcends everything else they do."* Coupled with the shared goal is a high level of mutual trust which comes out very clearly in interviews*: "Everyone trusts each other to be doing the best they can… That fundamental trust drives our particle physics group." "You have to trust that people will step up… and do the dirty work as well as doing the glamorous work*".

The involvement of users on the PMB keeps this goal, and its associated sense of urgency, in sharp focus. As one user highlighted: *"we spend a lot of our time, from the users point of view, trying to convince them just how important it is that this stuff works next year. And it if doesn't how deeply in trouble we all are from the funding point of view".* CERN borrowed heavily from its future funding in order to build the LHC and the future of the particle physics discipline may rest on its success. This highlights the pressures GridPP is under; pressure from funding agencies to achieve the objectives, pressure from LHC, as well as pressure to show the UK in a good light among the worldwide particle physics community.

GridPP is kept committed, engaged, and is always "just about" on top of things, constantly fire-fighting, discovering problems, managing crises, and negotiating solutions, as one interviewee described it. And yet there is a high level of confidence despite the sense of urgency and disorder on the surface. Almost everybody in the collaboration that we interviewed holds a firm belief that the Grid will work; it may not work perfectly, but it will work.

One source of this confidence is the particle physics community's long history of success in computing. CERN for example has accepted the problems of working with pre-production supercomputers from the days of the CDC 6600 through to the CRAY X-MP (Jones, 2004). Later they pioneered work on the Internet and developed the World Wide Web (Berners-Lee and Fischetti, 1997), shifted early to use Open-source (Linux) server-farms; and recently led early development of Grids (Lloyd, 2003) and GigaBit networks.

A perhaps more significant source of confidence resides however in the belief in the individual skill, competence and creativity of physicists, and in physics' formative context of collaboration. While GridPP employs people from other fields, the majority are from this "elite science" (Traweek, 1988) which is highly competitive to enter. When asked about the likely success of LCG a technical coordinator stated it bluntly "*Because we are very clever people, we have a very clear and determined goal, we will make it work*".

Working together is central to this formative context. "*We have a background in working in large teams and working with different sorts of people, different nationalities, different categories of people, students, technicians, engineers, physicists.*" (PMB Member). Drawing on (enacting) this experience is seen in the format of the GridPP collaboration. A member of the PMB comments, "… *the original proposal for GridPP was set up deliberately to make it look like an experiment. This whole idea of a collaboration board for instance, comes out of the idea of what an experiment does".*

Managing the unmanageable

Funding plays an important role in GridPP. While pragmatism, trial-and-error, and improvisation characterize the way GridPP is developed, such *ad hoc* practices are necessarily supported by financial planning, risk management, project milestones and resource allocation mechanisms as a requirement of getting funding. Extensive Gantt charts and schedules are produced, often in a preparation for funding council reviews, but these also serve as a minimal structure for the project. While the project manager was only appointed on the insistence of an IT industry representative sitting on the Oversight Committee, and the PMB finally settled on appointing a Particle Physicist (and "friend" of GridPP) to the post, this role is now accepted as crucial to keeping the project on track. This is not however to say that it focuses on traditional project management; *"we didn't want a commercial project manager because we felt that they would apply some of the conventional project management techniques which we didn't feel were applicable to this type of project"* (Senior member of PMB). Indeed one of the 'project managers' responses to the need to mix pre-composed and spontaneous activity within GridPP was to focus on planning for change. By considering GridPP as in its essence *"experimental"* and undertaking *"green-field research"* the PMB focused on supporting (and justifying) change as their minimal planning process. *"We wanted to establish the fact that we had the right to change our deliverables. So we set up this project map and we set up the formality of change forms. So this was to formalise our freedom to change the project and at the next Oversight Committee we managed to get this sort of structure through to them that yes, we had a set of milestones but you know, we had a mechanism to change them because we have to be responsive."* (PMB member). The project map and change forms become tools to avoid a pre-established plan and support (legitimize) spontaneity, but also ensure that members knows what is to be done, and that there is some impetus to carry the project forward, even if the plan is tentitive and has to be made real through their day-to-day sense-making and actions.

GridPP is *"committed to something that it isn't quite funded"* (PMB member). In March 2007 GridPP were approved of only 70% of the anticipated funding for phase three from 2007 to 2011. Not getting 100% of the resources means that some support posts are cut and solutions to reduce the impact of this lack of human support have to be found. GridPP's reliance on externally produced hardware and software also creates problems. For example an undocumented change in the firmware of a set of hard-disks included an error and had significant repercussions for GridPP in isolating this irregular error among terabytes of distributed storage. Similarly the release of a new version of the Scientific Linux operating system (on which LCG runs) created demands from some computer centers to upgrade GridPP to this new version (particularly where computing resources were shared with other disciplines), and yet EGEE's software only ran on an even earlier version. Further issues occurred when some centers purchased 64bit rather than 32bit CPUs, demanding two different distributions of the software.

To cope with such difficulties the project has to be flexible and always ready for changes. It has to rely on systems developers to come up with practical solutions, as they encounter them, being "amethodical", highly pragmatic and improvisational. This has caused some friction with the computer scientists in the project, who, by virtue of their training, aspire to a more plan-based methodological approach. A technical expert (non-physicist) commented on the pragmatism of physicists; "*they see the computing as a tool to get a job done. And if it requires you to wrap sellotape around it to get it to work, then they will wrap sellotape around it. The people who come from a computing background tend to, I think, have slightly purer model of how the computing should work. [They] get more frustrated with the perceived software deficiencies… physicists are happier with an ad hoc solution just to get the job done and push them through*". A physicist also highlighted this saying that while 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"*.

Dealing with systems development

The lack of formal processes in systems development is openly acknowledged in the community, and most think this serves well the prime purpose, to build a working system in a limited timescale. Free reign at the technical front is enabled and supported by a minimal level of technical bureaucracy or top-down command. "*This environment is based on, if you want, charismatic leadership and people doing things relatively independent but also having the freedom to do them, and not having to report every two minutes on what they are doing*". As mentioned earlier, the management structure serves more as communication channels between clusters of expertise than a hierarchy of authority. Individuals or groups in the project will try to solve a problem, develop a package, write a document, not because their line manager told them to, but because they felt that it was useful for the whole project. This is acknowledged by one of the senior PMB members: "*If you get someone who is very good, you don't over-manage them. You let them get on with it. And I think people feel that the management involved in software, formal software engineering, end up hampering the developers rather than really helping them*". There is as a consequence enormous respect for the technical knowledge at the "grass-root" level and a desire to avoid any over-managing. But this flexibility and experimental culture is acknowledged to involve new risks. The scale of the LHC is larger than anything undertaken before, and while there is confidence that the LCG will work, members of GridPP appreciate that historically particle physics relied on "parachuting in" committed, highly intelligent and hardworking "post-docs" to fix specific problems. But the complexity and scale of the LCG is recognized as presenting a significant challenge to this approach when the particles hits the detector.

A distinct feature of identifying and exploiting technical solutions in the project is the reliance on "natural selection". Rather than a solution's selection through social arbitrariness or political power, technical solutions compete with each other within the collaboration for a while until one of them wins out by forming more alliances (Callon, 1986) or others "die" in a natural course e.g. due to technical failures, low up-take, lack of funding or other circumstances. *"The cream comes to the top. Things that work win out and that's how we worked it. (…) Nobody knew what the right approach was so you try several approaches and some win, some loose"* (PMB member). This is not to say that politics does not exist, but the influence of powerful actors is dissipated, or contingent on sound technical judgment. For example, a technical coordinator commented "*nobody… even if they were the most politically powerful person in EGEE, can force a broken piece of software to be deployed, because they will lose their political influence if they do that*". This approach clearly relies upon a redundancy of expertise; innovation, and improvisation require the freedom to dedicate time to interests rather than pre-defined goals. As one senior CERN employee who shared an office with Tim Berners-Lee recounted: *"Tim had the freedom from this hierarchy, to spend a bit of time investigating something which was of interest to him and nobody else here said – 'oh it's a waste of time, never mind'. He was working on remote procedure calls. And out of it popped the web"*. However the cost of LHC has reduced the free funding available for such redundancy of expertise, in one CERN employees view, from *"110 percent"* of the funding required to *"80/90 percent of the resources you need to do the job"*, and led to the other form of redundancy, particularly of support staff at CERN.

An imagined and remembered Grid

The seemingly spontaneous and improvisational practices of those developing and managing GridPP are balanced by its reflexivity, maintained by continuous and extensive communication flows, what Knorr-Cetina (1999) refers to as physics' "fine grid of discourse", channeling individual knowledge into the collaboration and providing a sort of distributed cognition or collective imagination. This web of communication includes the complex network of boards, committees, and working groups, the on-line resources which document and remember the activity, and the informal meetings during conferences, chance meetings at CERN where UK visitors congregate in "Restaurant Number One" in the early evening to meet, and inevitably in the pub. This extensive communication embodies a strong sense of mutual monitoring and proactive sense-making, supported by more ephemeral but equally significant markers of shared identity such as logoed pens, sweets and posters; GridPP tee-shirts worn at conferences, and an intense focus on "disseminating" GridPP's successes. Mood is important too, and the 'going to the pub' signifies a lightening up, a license to be reflective and the extent to which being a physicist and in this collaboration is more than a job "*if you can go out together and you can identify the problems and let out steam about them"*.

A significant part of GridPP's activity, achieved by various means both formal and less formal, lies in monitoring, accounting for, and making sense of the behavior and performance of the system *so far*. Targets for service levels and regular data transfer and processing exercises (called service challenges) test the reliability and robustness of the system in terms of both hardware, networking and software. Indeed, much of the debate within GridPP centers on the results of tests and monitoring statistics. Interpreting such statistics is not straightforward or free of controversy. With a range of different service challenges undertaken regularly statements such as "*we have to understand what is causing this phenomenon"* or *"find out what is behind the data*" are commonly heard during meetings. In one of the PMB meeting the Tier-1 manager said, *"Last week the Tier-1 achieved 100% availability. Don't ask me how it happened but it happened."*, in contrast to his more usual statements like *"the Tier-1 was down several times last week and we are still not sure what caused it"*. Problems, reasons, and performance are discovered retrospectively rather than predicted, and this is supported by "transient constructs" such as availability tests, dash boards (see http://dashboard.cern.ch), metrics, and applications that trace and monitor behavior of different aspects of the system.

Similarly during the quarterly collaboration meetings most presentations are retrospective and reflexive and discussion and argument centers more on what has been achieved since the last meeting than on the future. Finally the academic demands to publish, and the funding agency's demands for "dissemination activity", require GridPP to continually construct retrospective narratives of its own activity. Our research access has been greatly facilitated by this, and our curious interests in "what is happening" has been accepted as quite understandable and even beneficial if it allows people to talk about the project. There is then Knorr-Cetina's (1999) "humming" of collaboration "with itself, about itself", which maintains a constant collective reflexivity, exemplifying Giddens (1984) "monitored character of the ongoing flow of social life" and which makes retrospective sense-making an inherent and natural component in their process of system development.

Paradoxes that power the Grid:

The account of GridPP reveals many of the improvisational paradoxes that we identified within the literature, and allows us to begin to understand how something as diffuse and distributed as GridPP and the LCG can nonetheless operate on the limits and borders of technical and scientific achievement. These paradoxes help us to understand the power of the improvisational approach and its ability to allow systems of such scale and scope to come into being.

Pragmatic creativity: Pragmatic creativity, as demonstrated by GridPP, has a sense of the here-and-now which, without a strong shared understanding, might hardly deliver creative outcomes. But drawing on their experimental culture, intellectual arrogance and history of success, such 'messing around' seems to add up despite the complexity and uncertainty.

Oriented drifting: The here-and-now activity is not undirected. While on an individual or small group level improvisation maybe spontaneous, random acts are unlikely to yield complex organizational arrangements like GridPP. Instead they retain (in part drawing on experimental tradition) sufficient minimal structures and plans to orient the elements of an otherwise drifting system.

Retrospective order: Surprisingly we find that history, tradition and taking time to look back (including a constant comparison with previous accelerator developments) provide a strong elements of the underlying order. Whether current activity is spontaneous and difficult to place within the larger scheme of activity seems less relevant than whether previous activity has been effectively integrated into the ongoing discourse. Significant effort is therefore put into accessing recent activity in order that it becomes part of the narrative, and for them the Grid is constructed of talk, thought and reflection.

Managed serendipity: Particle physicists possess an 'aesthetic of imperfection' (Weick, 1999) indeed they upset their computer scientists by their casual acceptance of the "good enough". In this way, and given just enough resources to draw upon, innovative solutions emerge and those with resilience survive. As they acknowledge this is not without cost both in wasted effort and in poor maintainability from lack of rigor, due process or documentation. But this "natural selection" (in their words) is seen by them as necessary in ensuring that only the most relevant ideas survival and those which do not survive are quickly replaced.

Collective individuality: Physicists are ambitious and competitive but they still need each other. While their research papers are published with hundreds of authors (Faulkner et al (2006) for example has 198 authors), they know who contributed what. Like elite players in any team sport they have to balance their own performance with the needs of the team expressed as shared goals. This demands fewer traditional managerial structures of performative assessment, but does demand a great deal of collaborative skills such as emotional communication, building of trust, and just "hanging out".

Anxious confidence: The LHC itself is eternally at risk[1], and national funding regimes for projects of this scale and duration can be fickle. Nobody believes it won't work but nobody will

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[1] Demonstrated by recent problems with the magnets at CERN http://www.timesonline.co.uk/tol/news/uk/article1626728.ece

deny that a lot of things can go wrong. Nonetheless, the prevailing mood of GridPP is one of confidence. Everything from their past and tradition is enrolled in the discourse of the project and drives their confidence.

5. Discussion and Conclusion

The case of GridPP, and the improvisational-paradoxes it reveals, appear to challenge existing ideas about plan-based development, and "amethodical" approaches. What we see here is a large scale organizational improvisation that takes us far beyond the conventional concept of agility as reflected in the IS literature. And yet there is still a sense that this deserves to be seen as an agile project and that the core values of the conventional agile methods are present. We therefore propose that the concept of agility needs to be rescaled to incorporate such distributed and collaborative systems development situations – what we term as *Scaled Agility* and which is embodied in a commitment to systems development through organizational improvisation.

The scaling of agility we refer to here has two distinct dimensions which move us away from the usual locus of agility as a 'method' applied within clearly delineated and reserved areas. It is scaled-up in absolute size (numbers of people, organizations, interrelationships); and scaled-out in terms of variety of activity and its distribution across a range of institutional and organizational settings, working practices, and locations. We then observe agility not essentially in tasks, and the methods applied to them, but in how people see the world and perform for each other; in project managers, dissemination officers, systems administrators, hardware specialists, and physicists. This Scaled Agility is not, as discussions of agility within larger software organizations often propose, a question of de-constructing or reshaping problems into smaller parts manageable by, and suitable for, agile methods (Beck and Andres, 2005, p112). Rather, the organizational improvisation that is GridPP is a manifestation of agility that encompasses every facet of this large collaborative project and derives its vigor from the paradoxical juxtapositions that arise. Certainly agility on such a scale cannot be simply a matter of methods, technique, or process but has to permeate the whole as a culture of improvisation and bricolage and an aesthetic of imperfection.

Our study reveals the paradoxical character of this Scaled Agility which presents an interesting example of the tension between action and structure familiar within the social and management sciences (Poole and van de Ven, 1989). In systems development structure dominates while action is downplayed. Even within agile approaches such as extreme programming the focus seems to remain on the 'thing' with a software deliverable as end-point, and action as subordinate (Beck and Andres, 2005). But GridPP, seen through the improvisational paradoxes, is revealed in a different light. Here action is to the fore and performance, recollection, conjecture and collective imagination are at the heart of both what is done and how, supported by (minimal) structure. Of course structure is not missing and what is here is not minimal in the sense of being simple, but it does play a very particular enabling role to maintain the reflexive 'hum' of the project. GridPP has a complex set of managerial bodies and institutional relationships but this is the minimal structure necessary to maintain coherence across time-space and to sustain the vital sense of community for the independent thinking actors. The usual boring things that such projects need cannot altogether be ignored either. While the *Agile Manifesto* suggests comprehensive documentation, processes, tools, and contract negotiation and planning as things to be downplayed, Scaled Agility suggests rather that such things must be marshaled or accommodated *within* the encompassing improvisational practice. This is exemplified by the way that GridPP subsumed project management into their improvisational ethos, and shows how they come to enact a sense of structure and coherence.

Scaled Agility is observed as chaotic and unfolding from which order emerges rather than being imposed. It is necessarily loosely connected and incoherently assembled, within a tentative and conjectural architecture such that constituent components can be, and are, reworkable or disposable. Such loose coupling ensures that disruptions to the whole system from *bricolage* produced components is avoided and that stability and continuity are maintained (Lanzara, 1999). Critically for this under-funded and 'bleeding edge' project, embedded in this imperfection, murkiness and sub-optimization are the opportunities for novel practices and forms that allow further combinations and transformation. The use of competition and natural selection allows GridPP to absorb dispersed and localized practices without arbitrary or centrally imposed decision-making process. While such competition may be inefficient from the perspective of resource optimizing systems development, Scaled Agility suggests such micro-inefficiencies are serving a larger purpose if 'good-enough' solutions come to the project through "contests of unfolding" (Knorr-Cetina, 1999), or processes of releasement (Ciborra, 2000).

To compete within this milieu individuals must have some slack as well as respect for technical knowledge. Collectively this mood is sustained, coordinated and protected by drawing upon and enacting very specific organizational configurations. In developing a Grid infrastructure they draw upon the tradition of experimental particle physics (where innovation and critical thought is revered) rather than the tradition of software engineering or computer science. Enduring social practices of "hanging out" and developing clusters of expertise allow them to talk and imagine – perhaps inefficient and redundant ideas from any corporate perspective – but able to generate for the project the essential collective mind and self knowledge (Knorr-Cetina, 1999, Weick, 1995).

We have sought here to reframe agility by giving it a theoretical basis drawn from the literature of organizational improvisation. Using these ideas we have shown how advanced science, often seen as unemotional, consisting of hard, cold methods and facts, embraces improvised agile methods on a huge scale. Faced with a distributed systems development challenge, their choice is for an improvised performance – large and diffuse, but still visionary, engaged, passionate, innovative, and emergent.

We cannot argue that such Scaled Agility is ideal or appropriate for any other context – GridPP's solutions are after all only "just-enough" for them, and their documentation is messy their systems difficult to maintain – but they do appear to be creating the system they need and the system that they can live with. Quantum theory tells us that we cannot predict the behavior of individual particles, but we can address them collectively as probabilities that will show order. In a similar way this study shows that improvisation and *bricolage*, seemingly *ad hoc* or chaotic, can scale up across time and space to reveal order, direction, and structure.

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