AGILITY, PARADOX AND ORGANIZATIONAL IMPROVISATION:

THE DEVELOPMENT OF *A PARTICLE PHYSICS* GRID

YINGQIN ZHENG, WILL VENTERS, TONY CORNFORD.

LONDON SCHOOL OF ECONOMICS, HOUGHTON STREET, LONDON, WC2A 2AE.

Abstract

This paper examines a systems development project in a global collaborative community in the field of high energy physics - the ongoing construction of the UK's particle physics grid (GridPP), itself part of the world's largest grid, the LHC (Large Hadron Collider) Computing Grid. We observe in this project a collective performance through which the grid is constructed in an agile manner. We identify this performance as an organizational improvisation where the sense of agility is expressed in a large distributed performance rather than well-specified anddeliberate systems development practices. The paper identifies and explores six improvisational paradoxes that lie at the heart of this performance and offers, through an analysis of the case using these paradoxes, theoretical and practical implications for agile systems development.

Key words: agility, improvisation, paradox, grid computing, particle physics

Pegasus Working Paper
Information Systems and Innovation Group
Department of Management, London School of Economics
Houghton Street, WC2A 2AE.
www.pegasus.lse.ac.uk

1. Introduction

Many recent innovations in systems development practices have legitimized a more fluid, exploratory and responsive style of development practice (Baskerville and Pries-Heje, 2004; Baskerville et al., 2006; Baskerville et al., 1992; Fowler and Highsmith, 2001; Truex et al., 2000). These attempts to move away from traditional formalism in systems development methodologies (e.g. Boehm 1988; DeMarco 1978; Yourdon 1989) echo the long-standing observation from the field that traditional methodologies are 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 help create a sense of coherence in day-to-day activities (Nandhakumar and Avison, 1999). Such observations have caused some to rethink the status of method and methodology in systems development. Ciborra (1998, 2002), for example, speaks of the crisis generated by an overdose of method and planning and the ontological assumptions it draws on, and asks us to “suspend the belief that behind the messy everyday reality there is a geometric universe” (Ciborra, 2002). His suggestion is to substitute formalism with new concerns for care, hospitality and cultivation. These and other challenges to the belief in method, as well as 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), and equally technology (Orlikowski, 2000), it probably makes sense to argue that information systems development practices need to support a strong contextual contingency and allow for “improvisational action and bricolage” (Bansler and Havn, 2003;).

The trends outlined above are reflected in much of the contemporary systems development movement where practices are increasingly oriented towards speed, responsiveness and flexibility. The practitioner literature includes many versions such as rapid prototyping or quick releases, placing much less emphasis on predefined procedures, specification and systematic methods (Beck and Andres 2005; Highsmith 2002; Williams and Cockburn 2003). These practices have been given names such as “high speed software development” (Baskerville et al., 2006), “short-cycle time systems development” (Baskerville and Pries-Heje, 2004), “web-based system development” (Kautz et al., 2007), and, most influentially, agile development (Conboy and Fitzgerald, 2004; Fowler and Highsmith, 2001, Highsmith 2002). Agile software development has established a large literature in the past few years, and an extensive following within the practitioner community, based on principles characterised by quickness, lightness and nimbleness (Highsmith, 2002) and on values such as collaboration, communication, simplicity and courage (Beck and Andres 2005).

But most studies of agile system development are still dominated by concerns with micro behaviour and related processes in designing and delivering software, with a lack of attention to organizational cultures, institutional conditions and environmental constraints (Abrahamsson et al., 2009, Adolph, 2006). This is surprising since, from the days of Brooks' classic 'The Mythical Man Month' (1979) and DeRamer and Kron's (1975) concepts of 'programming in the large', it has been acknowledged that systems of any size or complexity are developed within an organizational environment, and that this environment is as significant in shaping the character of the project and its outcomes as any particular practices. There is thus a need to study agility within the environment and institutional setting of development - as highlighted in a recent special issue editorial on agility (Abrahamsson et al., 2009) which concludes that "one of the most pressing issues is the need to develop a better understanding of the implementation of agility at the organizational level".

In this paper we study an emergent form of agile practice within a specific (and distinctive) organizational context – the development of a Computing Grid for the Large Hadron Collider at CERN (the LCG – LHC Computing Grid). The organizational context of LCG, reflecting that of particle physics (Knorr-Cetina, 1999, Traweek 1988), is highly distributed with the LCG being spread across 170 computing centres in 34 countries. Their Grid, a form of globally distributed computing system constituted of diverse software and hardware resources, has been under development since 2001 and is one of the world's largest (Brookhaven National Laboratories 2009, Economist, 2005). Mobilizing to build this Grid is a grand systems development challenge in technical, organizational, political and human terms. Developing the LCG is an example of large scale system development on a global basis and one which seems to exhibit a quality of agility. We observe in LCG fluid practices that serve as a continuous response to external and internal change, and continual acts of trial and error matched with pragmatic problem-solving approaches. Bricolage and *ad hoc* activities dominate day-to-day practices and there is a minimal (though vital) level of use of formal methodologies or centralized control. The people involved, mostly physicists or physicist-programmers with a few computer scientists, take pride not in methodological rigour, but in their pragmatic approach to "make it work".

Large-scale systems development projects similar to this have been studied before and are known to face many challenges. Curtis, Krasner and Iscoe (1988), for example, suggested that the three most salient and interrelated problems are: thin spread of application domain knowledge; fluctuating and conflicting requirements and; communication and coordination breakdowns. More recently it has been pointed out that agile systems development is difficult to scale (Reifer et al. 2003). Ramesh et al. (2006) discuss three major challenges faced by distributed development projects that seek to be agile: communication, lack of control and lack of trust. Various strategies have been proposed to address the issue of using an agile approach in globally distributed development projects, including developing collaboration tools (Flor 2006), aligning IT components (Lee, Banerjee et al. 2006), and striving for a balance between flexibility and rigor (Lee, DeLone et al. 2006). Yet few attempts have been made to directly theorize agility and distributed organizational dynamics. As a large distributed project LCG faces the issues common to such projects, and yet what is interesting about this case is that their response is resolutely not to employ rationalistic approaches (as most of the authors above propose), but rather to respond with a spirit of agility.

In response this paper presents an extended conceptualization of agility which does reflect the dynamic, collaborative and distributed practices we have found within the LCG. When reviewing agility within the literature we see two common approaches. The first sees agility as empirically validated small group methods and practices. The second sees agility as an organizational capability (Sambamurthy et al. 2003; Lee, DeLone et al., 2006; Adolph, 2006; Mathiassen and Pries-Heje, 2006), for example, a firms' sense-and-respond capabilities, or dynamic capabilities (Williams and Cockburn 2003), or the organizational capability to learn, to explore and to exploit knowledge (Mathiassen and Vainio, 2007; Overby et al., 2006). We propose here a third and distinct perspective on agility, what we call collective agility seen as a "structuring property" (Giddens, 1984) of a collective, which is instantiated in improvisational behaviour of individuals and groups and in their social interactions. In other words, collective agility is an attribute emergent from the day-to-day practices of social actors. We explore agility not only or principally as validated development practices or as an organizational capability, but as a *performance* (Barry, 2005; Ciborra, 1999; Dyba, 2000).

It is important to make clear the distinction between capability and performance: capability refers to the potential for achievement that an organization has as it draws upon its resources, human, institutional and material, a concept linked to the resource based view of the firm and core competencies (Wade and Hulland, 2004). In contrast, a performance is an enactment within a context that can create, apply and sustain capabilities. Put another way, capabilities are not understood as something held prior to a performance, rather they are both the medium and outcome of it. This ontological distinction allows us to study what is done, by whom, how, even in what mood (Ciborra, 2001), and out of which agility is expressed. The performative ontology (Pickering, 1995) allows us to see agility as what social actors might do when engaging with uncertainty and the complexity of their environment; this again is sustained by collective agency over time and space. Our focus is not then essentially on a description of agile behaviour or its precursors. Rather, the objective is to explore the collective agility found (performed) in the LCG project, with an emphasis on the emergence of this agility from disparate practices embedded in the organizational and cultural context. Put another way, our argument is not just that agile methods of systems development can be sustained in some particular supportive organizational or cultural context, but that the context or culture itself demands (at times) a certain type of agile performance.

To unpack the complexities of collective agility as an organizational performance, we draw upon the organizational improvisation literature (Cunha et al., 1999; Weick, 1998) with a focus on collective, collaborative and coordinated improvisational activity. Improvisation is essentially an individual practice, immediate and situated, whereas the agility we study is what emerges from a collective performance of an organizational improvisation. The literature we use is focused around the perspective of paradox. It has been frequently noted that innovations in development such as short cycle time development or agile methods often involve paradoxical elements, for example, learning to "plan not to plan" (Baskerville, 2006) or to achieve a "disciplined messiness" (Highsmith, 2002). Similarly, paradoxes manifest themselves in organizational improvisation (Mirvis 1998). The potential tensions in such approaches are endorsed Baskerville (2006) when he calls for a rejection of polar distinctions between concepts like planning and serendipity, or discipline and creativity. The concept of paradox used here is not intended to suggest a logical impossibility or irresolvable conflict, rather paradox provides a means of presenting and analysing productive tensions, dynamics, and motivating challenges of systems development. By constructing a set of improvisation-paradoxes, and applying them in the analysis of the case, we show that the embracing and balancing of such paradoxical elements is the key to understanding distributed collaborative systems development.

In short this paper concerns collective agility, a concept we introduce to describe a particular genre of organisational performance which exhibits the improvisational nature of agility but is not "agile" in the sense of a capability (i.e. a capacity to act), nor "agile" in the sense of using pre-defined agile systems development practices. Collective agility, as we observe it within our study of particle physicists constructing a global grid, exhibits paradoxical elements and we employ the concept of paradox to derive an analytical framework to help us understand it. From our analysis we see LCG enact improvisational work practices as the mutual constitution of paradoxical elements. Collective agility is emergent within the organisational performance of the collective, what we call enacted emergence.

The rest of the paper is as follows. Section 2 derives further the conceptual constructs of the paper; improvisation paradoxes drawn from the literature of organizational improvisation. Research methodology is presented in Section 3, followed in Section 4 by a case description of the distributed collaboration of the particle physics Grid focusing on their system development practices. Section 5 presents an in-depth analysis of the organizational performance of GridPP under the framework of improvisation paradoxes. Theoretical and practical implications are discussed in section 6 followed by our conclusions.

2. Improvisation Paradoxes and Enacted Emergence

Most existing research on organizational improvisation considers it essentially a creative group performance with little formal planning and minimal central control, as implied by the metaphor of jazz (Barrett, 1998, Hatch, 1999) or improvisational theatre (Crossan, 1998). 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*" (Cunha et al., 1999). This definition emphasizes two aspects. First, the temporal order of improvisations, and the convergence in time of conception and execution (Moorman and Miner, 1998), or “real-time planning” (Miner et al., 2001). This resonates strongly with the basic notion of agility as quickness, lightness, and nimbleness (Highsmith, 2002). Second, *bricolage* – the aspect of finding solutions from available rather than optimal resources – which is often implied or used interchangeably with improvisation (Weick 1993a, 1993b, Ciborra, 2002), and which may be considered as inseparable from the action of improvisation.

Within information systems, improvisation and *bricolage* have often been used to critique the dominant ontology of planning and control and the pervasive normative tendencies that follow (El Banna, 2006, Ciborra, 1999, 2002, Ciborra et al., 2000, Lanzara, 1999, Orlikowski, 1996). Yet despite an implicit, at times even explicit, challenge to the dominance of planning, control, and order, organizational improvisation literature does not necessarily seek to deny or negate the value of these concepts. 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. Our performative view of agility aims to allow us to reveal the working out or resolving of these tensions or paradoxes, i.e. the “tensions and oppositions between well-founded, well-reasoned, and well-supported alternative explanations of the same phenomenon” (Poole and van de Ven, 1989).

We are drawing upon the established tradition of using paradox as a dialectical device to examine complex situations and to build theory (Lewis, 2000; Poole and Van-de-Ven, 1989; Smith and Tushman, 2005). Lewis describes three categories of paradoxes prevalent in organizational studies – learning (old/new), organizing (control/flexibility), and belonging (self/other). Using these three categories as a guideline, we examine and synthesize the literature on organizational improvisation, and present a set of improvisation-paradoxes. Table 1 lists these constructed paradoxes with examples of the conceptual repertoire they draw upon.

[Insert Table 1 about here]

Paradoxes of Learning

Learning paradoxes arise from the tension between *old* and *new*, i.e. “the struggle between the comfort of the past and the uncertainty of the future”, which revolve around processes of innovation, transformation and sensemaking (Lewis, 2000). In organizational improvisation, the tension between old and new is reflected as tensions between the *immediate context* and the *historic*, and between *spontaneit*y and *reflexivity*. The paradoxes arising from these tensions are identified here as *Learned Improvisation*, i.e. improvisation based on past experience and situated within environmental constraints; and *Reflective Spontaneity*, namely, making sense via ex-post interpretation and rationalization.

- Learned Improvisation: Organizational improvisation can be seen to arise from the tension between the immediate (the here-and-now environment and context) and the historic (the interpreted, documented and remembered past). “Learning requires using, critiquing, and often destroying past understandings and practices to construct new and more complicated frames of references” (Lewis, 2000). Improvisation is often a response to uncertainty, and environmental turbulence (Moorman and Miner, 1998), although unexpected and “unplanned-for” (Miner et al., 2001) occurrences or tasks can arise inside the collective too (Cunha et al., 1999). For example, when the complexity of a task seems to be beyond the scope of rational planning, accumulated knowledge or predetermined method at a micro level (Hutchins, 1995). Organizational improvisation can also be linked to deliberate innovation – for example, 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).

In order to cope with uncertainties and complexities of the environment, people need to draw upon past experience and the repertoire of organizational memories as “learned ways of thinking and behaving” (Moorman and Miner, 1998). The paradox of *Learned Improvisation* thus also reflects the tension between the reliance on “habits of thought” and a will to depart from organizational traditions and norms (Cunha et al., 1999). This balance is quite intricate, as successful improvisations are often based on memory, practices and shared forms of collective improvisations established in the past (Weick, 1998). As Berliner (1994) describes jazz, “Improvisation depends, in fact, on thinkers having absorbed a broad base of musical knowledge, including myriad conventions that contribute to formulating ideas logically, cogently, and expressively.” Brown and Eisenhardt (1995) similarly suggest that in product development, firms with established routines are more likely to improvise than those without. The construct of “history” here is also related to collective understanding and organizational culture, e.g. the experimental culture of particle physics.

- Reflective Spontaneity: Weick (1998) too explores the jazz metaphor, and highlights the importance of retrospection. For example, in formal jazz study, musicians are supposed to be able to recall the music that has been performed and learn from it (Berliner, 1994). As mentioned above, improvisation draws on memory; thus “to improve memory is to gain retrospective access to a greater range of resources” (Weick, 1998). 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. In unplanned scenarios, improvisers often have no choice but to engage with the situation without the time for thorough reflection. The results are not always predictable, and the significance of the action is often only (re)discovered after the event. The tension of Reflective Spontaneity is therefore between spontaneity in the moment, and a collective reflexivity in a process of retrospective sensemaking. 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.). Retrospective sensemaking can also be facilitated by "transient constructs" (Lanzara, 1999), 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 an "emergent order" (Miner et al., 2001) which in turn can be drawn upon by others (Orlikowski, 2000). In contrast to "learned improvisation" in which the paradox concerns the link between disciplined practices in the past and the performance of creativity in the moment, for "reflective spontaneity" it is a paradox between *ad hoc* experimentation and *post hoc* recovering of rationalization by the collective.

Paradoxes of Organizing

Paradoxes of organizing are underlined by tensions between control and flexibility (Lewis, 2000), formal and informal, integration and differentiation (Chae and Bloodgood, 2006). It "denotes an ongoing process of equilibrating opposing forces that encourage commitment, trust, and creativity while maintaining efficiency, discipline, and order" (Lewis, 2000). There are two aspects to these tensions implicated in organizational improvisation which we summarize as *Planned Agility* and *Structured Chaos*. The former underlines the tension between the deliberate action of planning and the uncontrolled processes of drifting and unfolding; the latter refers to the tension between chaotic day-to-day practices and minimal structures which serve as a medium of the practices of exploration and trial-and-error.

- Planned Agility: Whether responsive or deliberate, improvisation is often 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, 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) puts it, "improvisation is a mixture of the pre-composed and the spontaneous". Researchers in improvisation often argue that the freedom to innovate is often the result of intense planning and careful orchestration (Mirvis, 1998). Miner et al (2001) for example suggest that organizations can "plan to improvise, routinize processes to stimulate improvisation, and routinize the observation of their own improvisational activities, all without the actual content of the improvisation being planned in advance".

Planning for improvisation encompasses two aspects; clearly articulated goals (Barrett, 1998; Ciborra, 1996; Crossan, et al., 1996; Orlikowski, 1996), and milestones and action deadlines (Cunha, et al., 1999). Clearly articulated goals provide a sense of direction in terms of organizational objectives and shared vision, often operating via culture or ideology (Mintzberg, 1995; Weick, 1993b), and serve as a ‘magnetic field’ which, without prescribing individual action, is strongly normative in shaping such action (Cunha, et al., 1999). Short-term milestones and deadlines build up a sense of momentum and urgency (e.g. Crossan, 1998, Hutchins, 1991, Mirvis, 1998). They also provide opportunities to keep track of the variations between dispersed innovative actions and priorities within the collective goal. In other words, even though day-to-day practices may be unplanned, *ad hoc*, and drifting (Ciborra, et al., 2000), minimal strategic planning and management can ensure that this drifting is appropriately oriented towards a clearly articulated goal, and when necessary can perform mutual adjustment between the goal and improvisations.

- Structured Chaos: Organizational improvisation might be seen as a form of “organized anarchy” characterized by problematic preferences, unclear technology, and fractured participation (Hutchins, 1991). Cunha et al (1999) suggest “minimal structure” to express the controls desired to achieve improvisations that progress (Crossan, 1998, Orlikowski, 1996, Weick, 1998). This minimal structure refers to a shared knowledge among members of a community of practice that allow for members to depart from canonical practice, especially when acting together (Brown and Duguid, 1991). A collateral structure (Cunha et al., 1999) provides non-intrusive support to learning communities allowing space for fluid and interpretative practices to take place across boundaries of groups (Brown and Duguid, 1991).

Minimal and collateral structures allow the cultivation of an “experimental culture” (Cunha et al., 1999) or pro-innovation culture (Miner, et al., 2001; Mirvis, 1998; Weick, 1998), which nurture individuality through features such as tolerance to error (Barrett, 1998; Crossan, 1998; Hatch, 1999). Weick proposes an “aesthetic of imperfection” as an important condition for improvisation, which “does not use as its standard, compliance with or deviation from some plan or ideal or blueprint. Instead, it uses as its standard, some estimate of the degree of organization and form that could have been extracted retrospectively from the materials at hand, given that they were generated by a fallible human being acting publicly under time pressure, with fallible tools” (Weick, 1999). Lanzara (1999) similarly talks of fractures, discontinuities, inconsistencies, deviations from current routines and puzzling or random behaviors in innovative processes. Yet imperfection and murkiness can embody evolutionary opportunities for novel practices and forms, and lead to further productive combinations and transformations.

Paradoxes of Belonging

Paradoxes of belonging arise “because actors strive for both self-expression and collective affiliation” (Lewis, 2000). This tension is particularly distinctive in improvisational activity, because by nature members of an improvisational collective tend to be intelligent and creative people; yet they also have an acute appreciation that success relies on collaborative effort. It is through trust and mutual support that they acquire confidence and strength in face of pressure and challenges. We adopt Mirvis’ (1998) two paradoxes of improvisation (both paradoxes of belonging), enriching them by linking them to organisational improvisation literature and theory. These paradoxes of belonging are *Collective Individuality* and *Anxious Confidence*.

- 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 a 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 (Miner, et al., 2001; Orlikowski, 1996) nurture 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 itself as a mood and contrasts it with conventional moods of the systems 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. Similarly, LaPorte (1996) (cited by Weick et al (1999)) speaks of 'prideful wariness' when discussing air traffic controllers. 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).

Paradoxes and Enacted Emergence

These improvisation paradoxes embody a sense of the tensions found in an agile performance, particularly in a distributed context. To capture this sense of dynamic duality we draw on two of Poole and van de Ven's (1989) four modes of working with paradoxes – to first accept the paradox and use them constructively, and also to introduce a new term or concept to resolve the paradox. In this spirit we propose the term "enacted emergence" to portray a paradoxical and agile performance that is both constructive and emergent.

Indeed, it has often been pointed out that information systems development is an emergent socio-technical activity (Baskerville and Pries-Heje, 2004; Chae and Poole, 2005; Orlikowski, 1996; Truex and Baskerville, 1998). The improvisation-paradoxes developed here juxtapose and reveal the seemingly opposite elements of improvisation, and can reveal the tension between environment and history, spontaneity and reflexivity, unfolding and planning, practices and structure, individual and collective, and anxiety and confidence. These seemingly opposite elements are bound together in a constant mutual constitution. Enacting elements on one side of Table 1 gives rise to elements on the other side, for example, a high level of planning, direction, but minimal structure provides the support, freedom and safety-net for people to explore through trial-and-error, improvise, and innovate. Seen the other way, seemingly disorderly and chaotic day-to-day practices can give rise to order, direction and meaning through retrospective sensemaking. Individuals are encouraged to keep their individuality and free thinking as the community cultivates a culture of democratic meritocracy, while a high level of creativity and competence, as well as the common goals shared by the members, can inspire trust, commitment and voluntarism.

Agility is a phenomenon of enacted emergence in the sense that, while it is rooted in creative human agency, i.e. the improvisational practices (including the dimensions of planning, organizing and structuring) of knowledgeable and reflective social actors (individuals and teams), agility is an attribute of the distributed collective, which emerges from the paradoxes and exists as a combination of intended and unintended consequences of these activity. In the following sections, we examine in detail as the GridPP community enact the improvisation paradoxes and manage to sustain a collective agility.

3. Research Methodology

The Large Hadron Collider Computing Grid provides a distinctive case of distributed systems development practice (Venters and Cornford, 2006). Our empirical work focuses on the UK's component of the project – GridPP. Data collection began in August 2006, following earlier pilot work, and included participant observations of weekly project management board meetings and deployment team meetings, quarterly GridPP collaboration meetings in the UK, international meetings of the whole LHC Grid project, site reviews carried out by GridPP, observation of various forums and conferences in which GridPP participates. The research team includes an experimental particle physicist to ensure the research is not undermined by a lack of understanding of physics. We have had full access to the GridPP main documentation, and subscribed to its main mailing lists.

Forty eight semi-structured qualitative interviews of between one and one and a half hours were undertaken at various universities across the UK and during two week-long periods at CERN in Geneva. Table 2 provides details of the research activities undertaken while Table 3 shows a summary of the principal interviewees. Interviews were audio-recorded, transcribed and then organized for analysis using the Atlas.Ti software**.** The software was used in handling the amount of data generated though not rigidly since we wished to avoid being restricted by the software. Data analysis was closely integrated with theoretical development in an iterative process, one feeding into the other.

[Insert Table 2 about here]

[Insert Table 3 about here]

We can identify three stages of data analysis. The first round was open coding of the data, labelling aspects of the project, their practices, and emerging ideas from the phenomena (Table 4 shows an example of the codes and quotations). This exercise, combined with the embedded understanding acquired by the researchers during secondary material research and participant observation, provided an appreciation of the complexity of the project and gave a sense of the tensions inherent in such work. For example, being experimental scientists, physicists are not keen on following given methods and procedures, preferring to think their way forward. Similarly, while there may seem to be a lot of adhocracy and fire-fighting in the project, they are unified in their confidence that "the system will work". With these broad ideas in mind, our theoretical exploration led us to the literature of organizational improvisation, which has a strong resonance with the data, and which already entails a paradoxical dimension (Weick, 1998). This gives rise to a draft analytical framework of improvisation paradoxes.

[Insert Table 4 about here]

In the second round of data analysis, we used the conceptual constructs from the improvisation-paradoxes as categories to set up code families in a way similar to axial coding in grounded theory (Corbin and Strauss, 2008). These codes are presented in a network view, and relationships between the codes were identified. But these relationships were not understood as indicating causality. In this process, some codes were merged, some became more general or more specific. Not all code families were included in our analysis, as some were considered interesting phenomena but not directly related to the key concepts. These "networks" were then validated against the data. This was an iterative process until the key conceptual constructs were sufficiently refined. It should be noted that we also verified our findings with a survey, not reported here, which largely confirm the themes derived from coding the interviews.

In summary the analysis reported here is the result of iterative reflections and ongoing discussions within the research team and with GridPP members, rather than a narrow machine-derived account –

our own engagement with organizational improvisation and sensemaking. While all the quotes given here are taken from interview transcripts, the ideas have also been significantly reinforced by informal conversations and participant observations.

This is not to say that the GridPP community is unified in their opinions. Tensions, conflicts and different views exist and are inevitable in any undertaking of this scale. Nevertheless, the research attempts to capture the distinctive features of GridPP, and this account has been broadly supported by three GridPP Project Management Board (PMB) members who were presented with the key findings of this paper.

4. The Particle Physics Grid

In October 2009 the Large Hadron Collider (LHC) particle accelerator at CERN, the European Laboratory for Particle Physics, began to collide Hadron particles at energies close to those of the Big Bang. The search was on for the elusive ‘Higgs-Boson’ particle believed to be responsible for matter having mass. These collisions will produce data for the LHCs four experiments (ATLAS, LHCb, ALICE and CMS). Since the Higgs-Boson is conjectured to be extremely rare (it has been likened to searching for a “needle in twenty million haystacks”) the number of collisions, and the subsequent data produced by the experiments, is vast. The LHC envisages producing 15 million gigabytes of data a year - equivalent to a DVD every 15 seconds or 1% of 2006 global information production (Lee et al., 2006). To store and analyze this data the LHC requires the equivalent of 100,000 PCs spread across the globe and working as a Grid (Britton, et al., 2004).

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

[Insert Figure 1 about here]

The GridPP project started in 2001 and has 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. As such GridPP is involved in developing applications and middleware as well as providing technical infrastructure including storage and processing units. As shown in Figure 1, the LCG has a hierarchically tiered structure, with Tier 0 at CERN, Tier 1s consisting of the national IT centers in each of the major countries involved in the project, and Tier 2s being the regional centers in each country. GridPP consists of the Rutherford Appleton Laboratory (RAL) as the Tier 1 centre, and four Tier 2 centers: London, ScotGrid, NorthGrid and SouthGrid, each coordinating a number of institutes in their region.

[Insert Figure 2 about here]

GridPP is managed, as with the wider LCG, as what one interviewee described as a “democratic meritocracy”. Figure 2 shows GridPP’s management structure which is better described as a network than any sort of hierarchy. The Project Management Board (PMB) is the heart of the network coordinating the project. It provides quarterly reports to the Collaboration Board which consists of representatives from the 19 institutes. The participating institutes enter the collaboration not under any legal obligation, but bound by a Memorandum of Understanding, which specifies the amount of resources and the level of service that each site is committed to provide, and the funding and support they will receive from GridPP in return. This document serves as a “gentlemen’s agreement” and there are no formal lines of authority between GridPP and the member institutes other than this collaborative relationship. Decisions have thus to be made on a democratic or consensual basis and implemented by influence and persuasion.

Developing LCG has been seen from the start as a highly distributed, complex and poorly defined systems development challenge. Cutting edge hardware and software is used, new software standards have to be negotiated, and middleware (the LCG grids ‘operating system’) along with a wide range of supporting software, is developed in a range of countries and programming languages. The grid is built on open source platforms (e.g. OpenGridForum software, EGEE middleware, Scientific Linux), and indeed the project shares some commonalities with open source activities. Yet the project also differs from most open source projects in that it is not, fundamentally, about delivering a piece of software or even a system, but about doing physics. It is developed with close involvement of members of the user community who exerts tremendous influence and pressure for the completion of a working system, which has to be achieved with limited time and resources.

The system development practices used within GridPP broadly coincide with the general principles of agile methods; “individuals and interactions over processes and tools; working software over comprehensive documentation; customer collaboration over contract negotiation; and responding to change over following a plan” (Fowler and Highsmith, 2001). A technical expert with experience of GridPP describes it rather more graphically as a “bottom-up approach”:

> *“You first write a code that solves the problem and then you understand how to take this code and make it work together with the other… but in the long term this may bring problems… At some point it breaks…”*

To be more specific, the systems development practices observed in this case are largely similar to the

ISD practices described by Baskerville and Pries-Heje (2004) as “short cycle time systems development”. Table 5 compares similarities and differences between ISD practices we observe and those summarized by Baskerville and Pries-Heje (2004). The final column of the table describes underlying organizational implications related to the identified practices. Beyond these similarities with other agile or short-cycle development projects, some challenges and characteristics of LCG and GridPP are distinctive, in particular, the scale of the system and the distributed nature of its own environment raising demands for scalability and interoperability. For example, LCG draws on several regional Grids in Europe, North America and Scandinavia each using different middleware. Within the European project, the middleware is modularized and its components developed in a variety of programming languages. Even though most middleware releases are tested in a small-scale pre-production system, they tend to be problematic when implemented across the whole system. The grid therefore evolves as advanced users actively engage in using, testing and reporting problems. In terms of system development cycles, there are not only simultaneous or overlapping activities of development, for example, design, development, coding, testing, maintenance, but also complete parallel solutions developed which then compete with each other. Finally, there are tensions around whether this grid should be generic enough for other communities of users (which it is in part funded to be), or whether it should be tailored to particle physics needs (who are the major users and developers); and tensions between the powers of system administrators of local sites, who might wish to prioritize the needs of their local institute, and the requirements of the conceptual Grid and the virtual organizations.

[Insert Table 5 about here]

5. Enacting Paradoxes

The enactment perspective proposed by Weick (1977) suggests that organizations “construct” their environment before they “respond” to it or try to control it, and this can be understood as a process of interacting and sensemaking. Enactment embodies the sense of action and creation. Indeed, Weick suggests that “people invent organizations and their environments and these inventions reside in ideas that participants have superimposed on any stream of experience” (ibid. p. 196). In this case, the particle physicists “reconstruct” the task of building a new distributed technology to be one that they are largely familiar with – a distributed experimental collaboration – and it can be seen as just another task that they have to complete in order to achieve the shared goal – doing new physics. They draw upon their experience in large experiments, competence in computing, their ability to work in large distributed groups, and their habit of breaking down a complex task into smaller pieces in order to investigate, tinker, experiment, and move forward by trial-and-error.

As introduced at the start of this paper, we frame the systems development activity in GridPP as an organizational improvisation that is animated by various tensions. This account is thus guided by the notions of paradox introduced earlier, used as a means to explore and express the countervailing forces that shape the performance of agility. We present our analysis, drawing on these paradoxes, in a slightly different sequence to Lewis. In this case we see the nature of the grid development as being fundamentally driven by a sense of *belonging* and start with this concept. We then move to paradoxes of *organizing* and conclude with *learning*.

5.1 Belonging to GridPP

There is a sense of a strong community bond among GridPP members, which we express in the concept of *collective individuality*. Most members of GridPP are particle physicists or have a physics background. One consequence is that members of the collaboration are motivated by a shared history and a shared goal, which is not essentially to build a grid, but more importantly to do new physics and try to understand the origins of the universe. They work for the same vision despite strong competition between similar experiments. As commented by one interviewee,

> *"I said I was proud of being a particle physicist, this is because 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 trust as came very clearly from the 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."*

> *"You have to establish goodwill and in order to have goodwill you have to have good communication and you have to have trust between people."*

Particle physicists have been encultured above all to respect intellectual capacity (Traweek, 1988). With the high level of trust, people generally enjoy a high level of autonomy at work, usually without clear instructions or strict supervision. Individuals in the project will try to solve a certain problem, develop a certain package, write a certain document, not because their line manager told them to, but because they felt that it was something useful to do for the whole project.

> *"I think people feel that the management involved in software, formal software engineering, end up hampering the developers rather than really helping them."*

On the other hand, with members of the collaboration based in disparate institutes, it is important to develop social and emotional bonds among individuals for the project to function collectively. The deployment team provides a good example.

> *"We have to work very well together as a team, in order for GridPP to be successful. And … it's quite a complicated structure - there are multiple channels of communication, some of which are duplicated some of which are contradictory, and there are all sorts of ways in which information flows. And anything that you can do to oil the cogs of the machine is going to help. And one of the things that is going on very well in GridPP is the cohesiveness of the deployment team. And I think for us to socialize together is a very important thing."*

"Going to the pub" when they meet, for example, is one aspect of this since it "fosters a bond" between people and allows them to discuss their frustrations caused by the size and complexity of the project. During such social occasions work is invariably discussed, people "let off steam" and accommodations are reached. These emotional communications support a mood of *anxious confidence*, a term borrowed from Mirvis (1998), which refers to the collective capability to handle tensions and anxiety, such as the pressure of the LHC switch-on and of showing the UK in a good light among the worldwide particle physics community. Apart from that, GridPP has to face many unplanned for occurrences and environmental turbulence in funding, human resources, external and internal technological changes, hardware and software configurations, technical requirements from the experiments, computer market conditions, and other institutional and political factors. The project is also "committed to something that it isn't quite funded" (PMB member). In March 2007 GridPP were allocated only 70% of the anticipated funding for phase three of GridPP from 2007 to 2011, which resulted in support posts being cut. Nevertheless, the collaboration remains committed, engaged, and always "just about" on top of things. They may seem to be constantly fire-fighting, discovering problems, managing crises, and negotiating solutions. But almost everybody in the collaboration who we interviewed held a firm belief that the Grid will work; maybe not perfectly, but it will work.

A significant source of this confidence resides in the belief in the individual skill, competence and pragmatic creativity of physicists, and in high energy 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 boils it down to cleverness:

> *"…because we are very clever people, we have a very clear and determined goal, we will make it work".*

Another source of this confidence (perhaps verging on arrogance) resides in the community's long history of success in computing. CERN for example 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 Web (Berners-Lee and Fischetti, 1997), shifted early to use Open-source (Linux) server-farms, all driven by the need to do physics.. Grid computing, it seems, is just another minor computing waypoint on the route to the truth about the universe.

Equally importantly, the particle physics community enjoys an organizational culture which appreciates "the aesthetic of imperfection" (Weick, 1999), providing a valuable safety-net for innovators and positively endorsing bricolage. 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".*

5.2 Organizing GridPP

Planned agility refers to planning to improvise and preparing for change. While improvisation is one way of coping with complexity and uncertainty, strategic planning can provide the foundation and direction necessary for a project. In GridPP it is recognised that *ad hoc* practices have to be supported by some financial planning, risk management, project milestones and resource allocation mechanisms. For this reason extensive Gantt charts and schedules are produced, often in a preparation for research funding council reviews, but also serving as a minimal structure for the project. While a 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 the PM role focuses on traditional project management. Considering GridPP as in its essence "experimental" and undertaking "green-field research", the PMB focus on supporting and justifying change as at the core of 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 … yes, we had a set of milestones but you know, we had a mechanism to change them because we have to be responsive. "*

Although schedules are constantly in flux, the project seeks never to lose sight of where they are and where they are heading.

> *"…people are looking at the overall targets of where people are trying to get to, rather than monitoring people on a daily or weekly basis. So we're looking for overall trends more than very small time-based ones."*

The project maps and schedules, change forms, and quarterly reports become tools designed to achieve various paradoxical goals; to displays rationalized order, to acquire legitimacy, to cope with changes and to support or legitimize spontaneity. They also provides impetus to carry the project forward, even if the plan is tentative and has to be made real through day-to-day sense-making and actions. This proactive mode of management is combined with a reactive mode of daily trouble-shooting:

> *"So we do everything we can in terms of advanced planning, so we have a staggered programme of sites in migrating, things like this. But ultimately what dominates is when we have done something that has gone wrong, or something has broken, or something doesn't work in experiments, or something like this, and we have to try and solve that."*

In other words, there is a plan to improvise, routinized processes to stimulate improvisation, and routinized observation of their own improvisational activities, without planning the content of improvisation in advance (Miner, et al., 2001). As one of the technical coordinators described, with an extended metaphor,

> *"You need your head in the clouds to see the big picture, but you very much need your feet on the ground because you have to put one foot in front of the other, and day to day we keep putting one foot in front of the other…."*

Structured chaos captures the essence of providing a minimal structure to support improvisation. GridPP is a collaboration of institutes who work together under a Memorandum of Understanding. Management in GridPP does not rely on vertical lines of command, and while there is an extensive structure of management boards, committees, and technical groups, they serve more as communication channels than hierarchies of authority. Managerial roles in the collaboration serve most of the time as representatives, spokesperson, or coordinating facilitators, and when decisions (e.g. financial planning) have to be made centrally at the PMB, such decisions are open to scrutiny by the full collaboration. Most importantly, there is enormous respect to the technical knowledge at the grass-root level. As one previous group leader stated:

> *"there's no strict hierarchy […] the group leader doesn't get to say what to do. In fact, I was extremely socialist [in my role as a group leader] 'cause we recognize it's the younger people that are much smarter and they're going to be making the papers … So it's kind of a federation, club… of smart academics who all want to do it and everyone trusts each other to be doing the best they can for the experiment. And that fundamental trust drives our particle physics group. "*

Different solutions often compete with each other within the collaboration for a while until one of them wins by forming more alliances or others die in a natural course e.g. due to technical failures, low up-take, lack of funding or other circumstances. The technical systems then emerge from "contests of unfolding" (Knorr-Cetina, 1999), so that the winning technology emerges as a fact of nature.

> *"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 lose ."*

The "natural selection" of technical solutions, as described by members of GridPP, allows elements of the grid to emerge from dispersed and localized practices without an arbitrary or centrally imposed decision-making process. Although the middleware is developed by a European Grid development project (EGEE) centrally coordinated at CERN, it is modularized and each of the components is prototyped, released, deployed, tested, and improved in an evolutionary manner. Beyond this core software there are often parallel technical solutions found in the project, such as some components of the middleware, or other software packages developed locally to help deploy, monitor, or manage aspects of the grid. The grid environment in this sense consists of a mixture of "ecosystems", in which multiple technical solutions may co-exist, may compete, and if so one of them may win out and the others "die a natural death". Political influence and vested interests are involved in such competition, but do not dictate the individual ecosystems. In this way the overall grid emerges. This is not to say that politics does not exist, but that they are dispersed, sidelined, and the influence of powerful actors is often dissipated, or contingent on sound technical judgment. For example, an interviewee commented that

> *"nobody, no matter, even if they were the most politically powerful person in EGEE, cannot force a broken piece of software to be deployed, because they will lose their political influence if they do that."*

5.3 Learning to perform

Learned improvisation refers to drawing upon past experience to cope with uncertainties and complexity of the present. The need to improvise in the grid project stems from the innovative and exploratory nature of the task: the process has to be trial-and-error since nobody knows what exactly the end product will look like. Moreover, the complexity of the project means no one person can have a clear idea of the whole system (Hutchins, 1991); requirements cannot be pre-specified in detail; architectures are conjectures, and even the only centrally designed piece of technology, the middleware, has to be modularized and released gradually rather than in a big-bang manner.

GridPP's reliance on externally produced hardware and software also creates problems, exposing them to external technological perturbations. Relying as they do on the EGEE to provide the middleware, they face an ongoing process of learning and adapting to immature software, and making it work at each individual sites. 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, requiring two different distributions of the software.

The response to this of those involved is not to control, 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 (Lewis, 2000). As Dahlbom and Mathiassen (1993) described, developers "have to interact with the environment, accept the openness of the problem and the system to be developed, take into account the preferences and beliefs of problem owners and users, deal with the economical and political climate of the project, and keep in step with the changes in the kind of technologies on which the project is dependent". Developers should be "scientific investigators" rather than "economic agents" (ibid.). Indeed, particle physicists clearly bring their identity as "scientific investigators" into computing.

> *"I think the people who come from a physics background are ultimately more pragmatic in computing. 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 physicists are happier with an ad hoc solution just to get the job done and push them through."*

Another senior member in LCG comments,

> *"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."*

One of the resources that GridPP draws upon is their identity as physists, and as noted the collaboration is designed as a physics experiment. The tradition of large scale collaborations (the ATLAS experiment, one of four at the LHC, has over two thousand members across the globe) and working on a distributed basis is well established and provides a solid basis for the improvisation of the Grid development project. As a PMB member commented,

> *"...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. And so I think we have somehow learned how to organise things so 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."*

In other words, the ability to improvise is the result of years of experience and learning. Such improvisation itself constitutes a further processes of exploration and reflection which feeds into the organizational capability to improvise.

Reflexive spontaneity indicates recovering meaning from improvisation retrospectively. The seemingly spontaneous practices at the low level are balanced by a level of reflexivity maintained by continuous and extensive communication flows. Particle physics collaborations are managed by what Knorr-Cetina (1999) refers to as "a fine grid of discourse", channelling individual knowledge into the collaboration and providing it with a sort of "distributed cognition". This web of communication includes a complex structure of boards, committees, and working groups which regularly hold meetings. One of the most important methods is the online virtual meeting. For example, the Project Management Board meeting takes place every Monday online where they discuss the status quo of the project and make action plans. The Deployment Team meets online on Tuesdays where they discuss technical issues. There are also many other meetings taking place virtually or face-to-face during the week. Wikis, webpages and blogs are consultation points in the meetings. More importantly, members of GridPP subscribe to various mailing lists that carry constant exchanges of up-to-date information on problems and emerging solutions.

Such extensive communications embody both mutual monitoring and proactive sensemaking. A significant part of GridPP's activity lies with monitoring, accounting, and making sense of the behaviour and performance of the system. Targets of service levels and regular data transfer exercises are used to test the reliability and robustness of the system, in terms of both hardware and software. Much GridPP debate revolves around the results of tests and monitoring statistics. Interpreting the statistics is not straightforward or free of controversy. It is common to hear comments like "we have to understand what is causing this phenomenon" or "find out what is behind the data". In other words, retrospective sensemaking is an inherent and natural component in their process of system development. There is a "humming" of the collaboration "with itself, about itself" (Knorr-Cetina, 1999), which maintains a constant collective reflexivity, as "the monitored character of the ongoing flow of social life" (Giddens, 1984).

6. Theoretical and Practical Implications

We have examined in the discussion above the characteristics of the collaborative performance of GridPP that enables them to achieve distributed agility. A set of improvisation-paradoxes of belonging, organizing and learning have been used to make sense of the way that the grid is developed within the particle physics community. In this section we reflect on the case material, draw implications for the wider discourse of agile systems development and provide some practical advice for those engaged in distributed systems development.

With multiple objectives and system development rationales in the community, the construction of Grid technology is a constant engagement and negotiation between a structured process and amethodical practices (Truex et al., 2000). Long term goals, shared aims, preset deliverables, regular monitoring and proactive political legitimization are entangled with an "unfolding ontology" (Knorr-Cetina, 1999) elements of which include: pragmatic outlook, fragmented and *ad hoc* practices, bricolage and improvised solutions, *post hoc* rationalization, as well as contested interests, internal competitions, and democratic decision making. We observe "a dialectic of resistance and accommodation" (Benson, 1977, Pickering 1995) in the organizational performance of the agile systems development.

We suggest that the particle physicists, while not following any pre-defined agile methods, are aware of the challenges they face and have made deliberate and substantial effort to achieve a suitable development process. In other words, the agility seen here is not just an "unintended consequence" of loose coupling, a culture of improvisation and bricolage, and intelligence, trust and pragmatism, rather it is performed by knowledgeable actors who draw upon and enact certain properties of a distributed collaboration, such as minimal structure, flexible planning, extensive communication and social bonding, all serving to generate coherence, facilitate mutual understanding and sense-making, and coordinate distributed work. The agency and knowledgeability of members of the Grid project are central in this. While no one serves as the mastermind of the project, the interaction and coordination among them give rise to a "collective mindfulness" (Carlo et al., 2004) with "a rich awareness of discriminatory detail and a capacity for action" (Weick et al., 1999). It takes effort to maintain this collective mindfulness, without which distributed agility would not be possible or sustainable. Therefore, while agility can be described as an emergent property of the distributed collaboration, such emergence is very much enacted, not without deliberation and reflection, as it is instantiated in day-to-day practices.

What practical implications can we draw from our analysis of this case of “collective agility”? We certainly do not believe the case presents an ideal form of distributed agile systems development - indeed much that is distinctive about the case is at odds with the canonical ideas of agile approaches. Yet the case does add to the studies on agile development in globally distributed projects and the perspective of improvisation paradoxes provides an opportunity to compare the practices of the case with practitioners practices. From the perspective of organizational performance, collective agility is about accepting what is unpredictable and uncontrollable, while actively enacting those organizational dimensions which enhance the capability to perform under such circumstances. Table 9 presents examples of such organizational practices from the case that could be useful to practitioners reflecting upon their own organisational practices and their desire to “be agile”. In the sections below, we explore further some of the possible practical implications of this view of agility by asking the questions of *when, what, who, where and how* is such case-specific collective agility *performed*. Our implications should be taken in the round – we see each as a cumulative recommendation rather than an isolated concept.

When is collective agility performed?

Agility is often necessary when faced with environmental turbulences, uncertainties, and in an innovative or exploratory task, as is the case with GridPP. Yet organizational improvisations come with risks and, for example, may not be the most efficient way to tackle certain problems, despite being preferred by a community reflecting on their past success. The particle physics community’s tradition of experimental scientific investigation and pragmatic way of problem-solving means an agile approach is “natural” rather than contrived, yet this also means it is “assumed” rather than “considered”. Overreliance of improvisation can also lead to an amplification of unexpected events and even crises, self-generating a negative spiral of uncertainties and complexities (Cunha et al., 1999). Communities engaging in large scale and distributed systems development are thus still faced with the challenge of getting the mixture of improvisation and structure right. As expressed by our concept of *learned improvisation*, we argue agility can (in a way) be learnt, and correspondingly, some structure is needed to support productive agility within the collective. Communities accustomed to more formal management approaches are not incapable of achieving agile performance. On the contrary, our research suggests, organizations with established routines and strong cultures to draw upon might be better equipped to improvise than those without, since agility requires “*disciplined* messiness” (Highsmith, 2002). What is needed is the cultivation of the space and motivation to diverge from or reinterpret established routines and context. Agility is performed when some “tools are dropped” (Weick, 1993a), and surprise, risk and wonder are accepted.

What is (the spirit of) collective agility?

We argue here that our collective agility is supported by a sustained mood of *anxious confidence*.

Anxiety stems from the nature of innovative tasks in the sense of urgency, pressure and demand for speed in problem solving. A successful innovative community needs a countervailing level of confidence which stems from strong individual skills and experience under demanding conditions, as well as exploiting a history of technical success. This confidence can arise in part from an appreciation for the "aesthetics of imperfection". The atmosphere of experimentation, trust, shared goal, and emotional bonds provides individuals and groups with confidence to explore and make mistakes, with the knowledge that failures are legitimate learning experiences, and when managed well, can ultimately contribute to the cause of the community.

Who undertakes collective agility?

Within GridPP the competence of the people, the level of determination and motivation, and how well the group gets on, were identified by GridPP members as the most positive aspects of the project. Performing collective agility poses a high demand on individual skills and mental attitudes. Like most professional domains, recruits are expected to be self-motivated, good communicators and able to work in a collaborative environment. Distinctively though GridPP prefers people who are familiar with the institutional culture of the particle physics community, and who are willing to step up and do the dirty work when necessary without leadership or explicit reward. The level of commitment, devotion and voluntarism appear higher than one might observe in a commercial context, though it feels similar to some high-performing consultancies. While individuals certainly have personal career interests at stake, many express a sense of pride in working for a higher cause, perhaps explaining their willingness to undertake unpopular tasks when needed.

Where does collective agility happen?

The literature suggests that both improvisation and agility are more easily performed in small groups, such as a jazz group or small development teams. Our case shows agility is possible in a large and distributed group, when the "ambience" is right, although achieving this is itself a major challenge (see also Ramesh, Cao, Mohan and Xu, 2006). The community bond is able to alleviate many difficulties but requires considerable effort to maintain. Even though the GridPP project members are accustomed to virtual meetings and large number of emails, they still emphasize the importance of face-to-face communication, and travel extensively to meet up. Of course, being reliant on delivery from many remote partners without the authority over them is often a source of frustration, thus the ability to exert gentle pressure, to persuade and to negotiate are important elements in coordinating a collective performance of agility. Barriers of communication or an overload of information can also create inefficiencies in a non-hierarchical community.

How is collective agility performed?

As has been repeated throughout the paper, agility requires a mental attitude to, in the words of one interviewee, “let go of control”, yet this does not mean anarchy. High level planning and a minimal structure are required. For GridPP this consists of alignment with common goals, a clear orientation towards the LHC objectives, a shared culture among participants, and a carefully crafted minimal structure of project management, as well as communication channels which allow local “clusters of expertise” to interact generating synergy and coherence. It is important that improvisation at the local level is complimented by structuring at the distributed level to maintain cohesiveness across the project and to create a sense of community among the independent-thinking actors. Finally organizational improvisation comes with risks. A lack of formal planning and reflexivity may mean that very little exploitation of novel ideas and knowledge occurs despite a great deal of exploration, thus creating “opportunity traps”.

7. Conclusions

This paper considers agile system development practice from the perspective of organizational performance, reflecting an understanding that systems development processes and activities cannot be discussed in a vacuum but must be considered in terms of how, in given contexts, they become embodied within a set of roles, attitudes and working practices adopted by people – as a *performance*.

From this case study we observe that the LHC-Grid unfolds in a constant negotiation and mediation between design and bricolage (‘working things out’), between planning and improvisation, and between enough success and tolerable and instructive failure. Drawing on previous work on paradox we construct a set of improvisational paradoxes as a framework to examine system development practices within this distributed development context. This framework, and the attention to performance, enables us to elaborate and explore elements often pushed to the background in discussions of system development, such as environmental conditions, individual skills, professional cultures, organizational structures, communication patterns, and interpersonal relationships. The case study demonstrates that computing infrastructure development in this perhaps most rationalistic and analytical of communities, is actually more like an “art” – visionary, experiential, passionate, agile and emergent.

The contributions made through this research are, we believe, threefold.

First we provide a conceptualization of agility that differs from the more common concerns with agile methods and behaviour, or with an organization’s agile potential or capabilities. In contrast, we develop an understanding of agility through the concept of enacted emergence (agility for us being an expression of what people do or achieve, rather than what they might do or capabilities they hold). We argue that the collective agility we observe in action emerges from improvisational activities undertaken by the members of the distributed project. Enacted emergence is the process at the core of this performance of systems development as various actors within GridPP develop their roles drawing on their history and contexts.

Second, to give a stronger conceptualization to the work of GridPP members as they enact a development process and as they work through (navigate/negotiate) the contradictory pressures for order and innovation, we derive improvisation-paradoxes from the literature. These are used as a way to conceptualize the dynamics of the agile performance as an expression of, and (to a degree) the resolution of, fundamental tensions. It is the mutual constitution of elements in tension that allow agility (an agile performance) to emerge.

Third, we offer a contribution to practice through this analysis, providing a set of recommendations of whenwhat, who, where and how of collective agility. These recommendations highlight the means by which collective agility might be achieved and maintained, and can offer instructive lessons to other domains attempting to construct large-scaled distributed infrastructure in an agile fashion. For example, Ramesh et al (2006) assert that distributed agility faces the challenge of communication, lack of control and lack of trust. Our study suggests that these may not be causes but symptoms of a broader failing to understand the nature of agility within such a context. Managers who want to achieve some of the attributes of agile performance, we suggest that the focus should not be upon engendering communication, control and trust *per se* (as Ramesh et al argues), but on supporting and shaping the performance of individuals and teams. Through this communication, control and trust can emerge as part of the collective work practices.

Finally the model of ‘enacted emergence’ of collective agility presented here highlights the need for ongoing performances - agility is not a “per project” or even less, “per phase” activity and cannot be achieved by a top-down “change programme”. Rather it is a performance that is reflective of collective organisational practice. Hence, achieving it is a long-term aspiration requiring attention and adjustments over time, and like other institutional factors, collective agility may be fragile and easily broken. For LCG it may be that the future will indeed be different, and contractual relationships, backbiting and a reliance on technical and managerial rationality will prevail once the LHC data begins and as pressure to deliver ‘outputs’ intensifies (though those interviewed see this as unlikely). What is clear is that many domains have much to learn from this case and the paradoxical nature of collective agility within the LCG.

References

Abrahamsson, P., K. Conboy, et al. "Editorial: ‘Lots done, more to do’: the current state of agile systems development research." European Journal of Information Systems (18), 2009, pp. 281-284.

Ackerman, M.S. and C.A. Halverson, "Considering an Organization's Memory," Proceedings of the the ACM Conference on Computer Supported Cooperated Work (CSCW'98), New York, 1998, 39-48.

Adolph, S. "What Lessons Can the Agile Community Learn From a Maverick Fighter Pilot," Proceedings of the AGILE 2006 Conference IEEE Computer Society Minneapolis, Minnesota, USA, 2006.

Bansler, J., and Bodker, K. "A Reappraisal of Structured Analysis: Design in an Organisational Context," *ACM transactions on Information Systems* (11:2), April 1993 , pp 165-193.

Bansler, J.P., and Havn, E.C. "Improvisation in Information Systems Development," Information Systems Research: Relevant Theory and Informed Practice (IFIP 8.2), Kluwer Academic Publishers, Manchester,UK, 2004, pp. 631-646.

Barrett, F.J. "Coda: Creativity and Improvisation in Jazz and Organizations: Implications for Organizational Learning," Organization Science (9:5), 1998, pp. 605-622.

Barry, C. "Decision-making and Information Systems Development - a Conceptual Framework," 13th European Conference on Information Systems (ECIS), Regensburg, Germany, 2005.

Baskerville, R. and Pries-Heje, J. "Short Cycle Time Systems Development" Information Systems Journal (14:3), 2004, pp. 237-264.

Baskerville, R.L. "Artful Planning," European Journal of Information Systems (15), 2006, pp. 113-115.

Baskerville, R., Ramesh, B., Pries-Heje, J., and Levine, L. "High-speed software development practices: What works, what doesn’t.," IEEE IT Professional (8) 2006, pp 29-36.

Baskerville, R., Travis, J., and Truex, D. "Systems without method: the impact of new technologies on information systems projects," in: The impact of computer supported technologies on information systems development, K.E. Kendall, K. Lyytinen and J.I. DeGross (eds.), North-Holland,, Amsterdam, 1992, pp. 241-269.

Beck, K., and Andres, C. *Extreme Programming Explained* Addison-Wesley, Upper Sadle River, NJ, 2005.

Benson, J.K. "Organizations: A dialectical view," Administrative Science Quarterly (22) 1977.

Berliner, P.F., Thinking In Jazz: The Infinite Art of Improvisation, The University of Chicago Press, 1994.

Berners-Lee, T., and Fischetti, M. Weaving the Web, Harper, San Francisco, CA, 1997.

Boehm, B. "A spiral model of software development and enhancement," *Computer* (21:5), May 1988, pp 61-72.

Britton, D, P Clark, J Coles, D Colling, A Doyle, SM Fisher, AC Irving, J Jensen, A McNaband D Newbold, "A Grid for Particle Physics - from testbed to production," GridPP, 2004.

Brooks, F The Mythical Man-Month, Addison-Wesley, New York. DeRemer, Frank; 1979

Brown, John Seely and Paul Duguid, "Organizational Learning and Communities-of-Practice: Toward a Unified View of Working, Learning, and Innovation," Organization Science, Special Issue: Organizational Learning: Papers in Honor of (and by) James G., (2: 1), 1991, pp. 40-57.

Brown, S.L. and K.M. Eisenhardt, "Product Development: Past Research, Present Findings and Future Directions," Academy of Management Review, (20: 2), 1995, pp.343-378.

Brookhaven National Laboratories, “Data-Taking Dress Rehearsal Proves World’s Largest Computing Grid is Ready for LHC Restart”, Brookhaven National Laboratory Press Releases, July 1, 2009.

Carlo, J.L., Lyytinen, K. & Boland, R.J., 2004. “Systemic Risk, IT Artifacts, and High Reliability Organizations: A Case of Constructing a Radical Architecture”. Sprouts: Working Papers on Information Environments, Systems and Organizations, 4(2).

Chae, B., and Bloodgood, J.M. "The Paradoxes of Knowledge Management: An Eastern Philosophical Perspective," Information and Organization (16) 2006, pp 1-26.

Chae, B., and Poole, M.S. "Surface of Emergence in Systems Development," European Journal of Information Systems (14) 2005, pp 19-36.

Ciborra, C. "A Theory of Information Systems Based on Improvisation," In Rethinking Management Information Systems, W. Currie and B. Galliers (eds.), Oxford University Press, Oxford, 1999, pp. 136-155.

Ciborra, C.U. "In the Mood for Knowledge: A new study of improvisation," in: Social Study of Information Technology Workshop London School of Economics and Political Science, London, 2001.

Ciborra, C. The Labyrinths of Information, Oxford University Press, 2002.

Ciborra, C., and Lanzara, G.F. "Formative Contexts and Information Technology: Understanding the Dynamics of Innovation in Organizations," Accounting, Management and Information Technologies (4:2) 1994, pp 61-86.

Ciborra, C., Braa, K., Cordella, A., Dahlbom, B., Failla, A., Hanseth, O., Hepsø, V., Ljungberg, J., Monteiro, E., and Simon, K.A., From Control to Drift: The Dynamics of Global Information Infrastructures, Oxford University Press, 2000.

Cohen, M.D., et al. "A Garbage Can Model of Organizational Choice," Administrative Science Quarterly (17:1), 1972, pp. 1-25.

Conboy, K., and Fitzgerald, B. "Toward a Conceptual Framework of Agile Methods: A Study of Agility in Different Disciplines," Proceedings of the WISER'04, Newport Beach, California, 2004.

Corbin, J., and Strauss, A. Basics of Qualitative Research, Sage, Los Angeles, 2008.

Crossan, M.M. "Improvisation in Action," Organization Science (9:5), 1998, pp. 593-599.

Crossan, M.M., et al. "The Improvising Organization: Where Planning Meets Opportunity," Organization Dynamics (24:4), 1996, pp. 20-35.

Cunha, M.P.e., Cunha, J.V.d., and Kamoche, K. "Organizational improvisation: What, when, how and why," International Journal of Management Reviews (1:3) 1999, pp 299-341.

Curtis, B., H. Krasner, and Iscoe N. "A Field Study of the Software Design Process for Large Systems." Communications of the ACM (31:11) 1988, pp.1268-1287.

Dahlbom, B., and Mathiassen, L. Computers in Context: The Philosophy and Practice of Systems Design, Malden, USA, 1993.

DeMarco, T. Structured Analysis and Systems Specification Yourdon - Prentice-Hall Software, New York, 1978.

DeRemer, Frank and Kron, Hans, "Programming-in-the large versus programming-in-the-small". Proceedings of the international conference on Reliable software: 114--121, Los Angeles, California: ACM, 1975.

Dyba, T. "Improvisation in small software organizations," IEEE Software (Sept/Oct) 2000, pp 82-87.

The Economist "One grid to rule them all.," in: Economist, 2005, Issue 8396, (2005) p. 74.

Elbanna, A. "The validity of the improvisation argument in the implementation of rigid technology: the case of ERP systems," Journal of Information Technology (21:3) 2006, pp 165-175.

Flor, N.V. “Globally distributed software development and pair programming”, Communication of ACM, 49(10), 2006 pp.57-58.

Foster, I., et al. "The Anatomy of the Grid: Enabling Scalable Virtual Organizations," The International Journal of High Performance Computing Applications (15:3), 2001, pp. 200-222.

Fowler, M., and Highsmith, J. "The Agile Manifesto," Software Development (August), 2001.

Giddens, A. The Constitution of Society: Outline of the Theory of Structuration, Polity Press, Cambridge, 1984.

Hatch, M.J. "Exploring the Empty Spaces of Organizing: How Improvisational Jazz Helps Redescribe Organizational Structure," Organization Studies (20:1), 1999, pp. 75-100.

Highsmith, J. "Agility in Software Development," In Agile Software Development Ecosystems, J. Highsmith (ed.) Addison Wesley Professional, 2002.

Hutchins, E. "Organizing Work by Adaptation," Organization Science (2:1), 1991, pp. 14-39.

Hutchins, E. Cognition in the Wild, the MIT Press, Cambridge, MA, 1995.

Jones, C. "Computing at CERN: The Mainframe Era," CERN Courier (44:7), 2004, pp. 32-35.

Kamoche, K., Cunha, M.P.E., and Vieira da Cunha, J. "Towards a Theory of Organizational Improvisation: Looking Beyond the Jazz Metaphor," Journal of Management Studies (40) 2003, pp. 2023-2051.

Kautz, K., Madsen, S., and Nørbjerg, J. "Persistent problems and practices in information systems development," Information Systems Journal (17) 2007, pp 217-239.

Knorr-Cetina, K. Epistemic Cultures: How the Sciences Make Knowledge, Harvard University Press, Cambridge, MA, 1999.

Lanzara, G.F. "Between Transient Constructs and Persistent Structures: Designing Systems in Action," Journal of Strategic Information Systems (8), 1999, pp. 331-349.

Lee, O.-K., Banerjee, P., Lim, K.H., Kumar, K., Hillegersberg, J.v., and Wei, K.K. "Aligning IT Components to Achieve Agility in Globally Distributed System Development," Communications of the ACM (49:10) 2006, pp 49-54.

Lee, G., DeLone, W. & Espinosa, J.A.“Ambidextrous coping strategies in globally distributed software development projects”. Communications of ACM, 49(10), 2006 pp.35-40.

Lewis, M. "Exploring paradox: Toward a more comprehensive guide," Academy of Management Review (25:1) 2000, pp. 760-776.

Lloyd, S. "GridPP - from Web to Grid," Frontiers (16), 2003.

Madsen, S., Kautz, K., and Vidgen, R. "A framework for understanding how a unique and local IS development method emerges in practice," European Journal of Information Systems (15) 2006, pp 225-238.

Mathiassen, L., and Pries-Heje, J. "Business Agility and Diffusion of Information Technology," European Journal of Information Systems (15) 2006, pp 116-119.

Mathiassen, L., and Vainio, A.M. "Dynamic Capabilities in Small Software Firms: A Sense-and-response Approach," IEEE Transaction of Engineering Management (54:3) 2007.

Miner, A.S., et al. "Organizational Improvisation and Learning: A Field Study," Administrative Science Quarterly (46), 2001, pp. 304-337.

Mintzberg, H. "The structuring of organizations," in: The Strategy Process: European Edition, H. Mintzberg, J.B. Quinn and S. Ghoshal (eds.), Prentice Hall Europe, Hertfordshire, 1995, pp. 350-371.

Mintzberg, H., and McHugh, A. "Strategy Formation in an Adhocracy," Administrative Science Quarterly (30), 1985, pp. 160-197.

Mirvis, P.H. "Variations on a Theme: Practice Improvisation," Organization science (9:5), 1998, pp. 586-592.

Moorman, C., and Miner, A.S. "The Convergence of Planning and Execution: Improvisation in New Product Development," Journal of Marketing (62:3), 1998, pp. 1-20.

Nandhakumar, J., and Avison, D.E. "The Fiction of Methodological Development: a Field Study of Information Systems Development," *Information Technology & People* (12:2) 1999, pp.176-191.

Orlikowski, W. "Improvising Organizational Transformation over Time: A Situated Change Perspective," Information Systems Research (7:1), 1996, pp. 63-92.

Orlikowski, W.J. "Using Technology and Constituting Structures: A Practice Lens for Studying Technology in Organizations," Organization Science (11:4), 2000, pp. 404-428.

Overby, E., Bharadwaj, A., and Sambamurthy, V. "Enterprise Agility and the Enabling Role of Information Technology," European Journal of Information Systems (15:2) 2006.

Parnas, D., and Clements, P. "A Rational Design Process: How and Why To Fake It," IEEE Transaction of software engineering, 1986, pp 346-357.

Pickering, A. (1995), The Mangle of Practice: Time, Agency and Science, University Of Chicago Press

Poole, M.S., and van-de-Ven, A.H. "Using Paradox to Build Management and Organization Theories," The Academy of Management Review (14:4), 1989, pp. 562-578.

B Ramesh, L Cao, K Mohan, and Xu, P. “Can Distributed Software Development Be Agile”, Communications of the ACM, 49(10), 2006, pp.41- 46.

Reifer, Donald J., Frank Maurer, and Hakan Erdogmus. 2003. “Scaling Agile Methods”. IEEE Software, July/August: pp. 12-14.

Sambamurthy, V., Anandhi Bharadwaj, and Varun Grover. 2003. “Shaping Agility through Digital Options: Reconceptualizing the Role of Information Technology in Contemporary Firms” MIS Quarterly(27), pp.237-263.

Smith, W.K., and Tushman, M.L. "Managing strategic contradictions: A top management model for managing innovation streams," Organization Science (16:5) 2005.

Traweek, S. Beamtimes and Lifetimes: The World of High Energy Physicists, Harvard University Press, London, 1988.

Truex, D., Baskerville, R. and Travis J. "Amethodical Systems Development: The Deferred Meaning of Systems Development Methods," Accounting, Management and Information Technology (10), 2000, pp. 53-79.

Truex, D.P., and Baskerville, R. "Deep Structure or Emergence Theory: Contrasting Theoretical Foundations for Information Systems Development," Information Systems Journal (8), 1998, pp. 99-118.

Venters, W., and Cornford, T. "Introducing Pegasus: An Ethnographic Research Project Studying the Use of Grid Technologies by the UK Particle Physics Community," Proceedings of the National e-Science Center Conference, Manchester, 2006.

Wade, M., and Hulland, J. "The Resource Based View and Information Systems Research: Review, Extension and Suggestions for Future Research". MIS Quarterly, (28:1), pp. 107-138.

Weick, K.E. "Enactment Processes in Organizations," In Making Sense of the Organization (2001), K. E. Weick (ed.) Blackwell, 1977.

Weick, K.E. "The Collapse of Sensemaking in Organizations: The Mann Gulch Disaster," Administrative Science Quarterly (38), 1993a, pp. 628-652.

Weick, K.E. "Organizational Redesign as Improvisation," In Organizational Change and Redesign: Ideas and Insights for Improving Performance, G. P. Huber and W. H. Glick (eds.), Oxford University Press, New York, 1993b, pp. 346-379.

Weick, K.E. "Improvisation as a Mindset for Organizational Analysis," Organization Science (9:5), 1998, pp. 543-555.

Weick, K.E. "The Aesthetic of Imperfection in Orchestras and Organizations," in: Readings in Organization Science, M.P. Cunha and C.A. Marques (eds.), ISPA., Lisbon, 1999.

Weick, K.E. "Enactment Processes in Organizations," In Making Sense of the Organization, K. E. Weick (ed.) Blackwell, Malden, MA, 2001.

Weick, K.E., and Roberts, K.H. "Collective Mind in Organizations: Heedful Interrelating on Flight Decks," Administrative Science Quarterly (38), 1993, pp. 357-381.

Weick, K. E. Sutcliffe, K. M. Obstfeld, D. "Organizing and the Process of Sensemaking," Organization Science (16:4), 1999, pp. 409-421

Williams, L., and Cockburn, A. "Agile Software Development: It's About Feedback and Change," IEEE (June), 2003.

Yourdon, E. Modern Structured Analysis Prentice Hall International, New York, 1989.

Paradoxes of Learning

	Immediate	Historic
Learned Improvisation	environmental turbulence (Moorman and Miner, 1998, Ciborra, 1996) task uncertainty (Miner et al., 2001) task complexity (Hutchins, 1995, Weick and Roberts, 1993)	organizational memory (Ackerman and Halverson, 1998; Moorman and Miner, 1998; Weick, 1998) Routines (Hutchins, 1995, Weick and Roberts, 1993) Practicing (Moorman and Miner, 1998; Weick, 1998)
	Spontaneity	**Reflexivity**
Reflective Spontaneity	convergence of planning and execution (Moorman and Miner, 1998) mixing the pre-composed and the spontaneous(Weick, 1998) drop your tools (Weick, 1993a) trial and error, *bricolage* (Lanzara, 1999)	retrospective sense-making (Weick, 1993b) *ex-post* interpretation (Lanzara, 1999) transient constructs (Lanzara, 1999)

Paradoxes of Organizing

	Unfolding	Planning
Planned Agility	organized anarchy (Cohen et al., 1972) a sense of urgency (Crossan, 1998, Hutchins, 1991, Mirvis, 1998) Flow (Hatch, 1999)	visions (Hatch, 1999, Mintzberg and McHugh, 1985, Hutchins, 1991, Weick, 1993b) plan to improvise (Miner et al., 2001) artful planning (Baskerville, 2006) temporality (Hatch, 1999) a sense of urgency (Crossan, 1998, Hutchins, 1991, Mirvis, 1998)
	Practices	**Structure**
Structured Chaos	organized anarchy (Cohen et al., 1972) knowing in practice (Orlikowski, 2002) murkiness (Lanzara, 1999) ambiguity (Hatch, 1999)	minimal structure (Cunha et al., 1999) collateral structure (Cunha et al., 1999) aesthetic of imperfection (Weick, 1999)

Paradoxes of Belonging

	Individuals	Collectivity
Collective Individuality	individual skills (Brown and Duguid, 1991; Mirvis, 1998) creativity (Barrett, 1998; Hatch, 1999; Kamoche, et al., 2003)	facilitative leadership (Crossan, 1998) trust and kinship (Crossan, 1998, Weick, 1993a) emotional communication (Hatch, 1999) fluid communication (Orlikowski, 1996, Miner et al., 2001)
	Anxiety	**Confidence**
Anxious Confidence	anxiety (Cunha, et al., 1999; Mirvis, 1998) moods (Ciborra, 2002) emotionality (Hatch, 1999) sense of urgency (Crossan, 1998, Hutchins, 1991, Mirvis, 1998)	individual skills (Brown and Duguid, 1991; Mirvis, 1998) aesthetic of imperfection (Weick, 1999) formative context (Ciborra and Lanzara, 1994)

Table 1. Tensions and Paradoxes in Organizational Improvisation

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

Table 2. Details of research activities.

Roles of Interviewees	**Number**	**Notes**
GridPP PMB members	12	Including project leaders, representatives of all other major boards, and liaisons with other partners.
GridPP technical experts	15	e.g. Tier 1 manager, Tier 2 manager, technical coordinator, deployment, sys-admins, other software developers
Active physicists	9	Often overlapping with other roles
Middleware developers	5	
LCG technical experts	11	e.g. LCG Grid deployment, experiment integrator, other software developers

Table 3. Details of interviews.

Quotations	Interviewee	Codes
I'm trying not to use the word senior to imply there's a real hierarchy. I mean people get promoted to be professor or whatever but it really hasn't nothing to do with the way it works, okay? That's internal to the university. So um, those people that you know, formally might seem more senior, this is relevant, their peers with people like [XXXX] and you know, really rely on people like that to make it work technically. So they're fully trusted to just get on with it in the deployment board. Okay? So it's a fairly flat structure really. There's no, there's no company-like structure of management board sets policy and another group sets something else and then you know, down the bottom, people do what they're told. It's nothing like that at all.	Member of Project Management Board	[collaboration] [democratic meritocracy] [flat structure] [mutual respect]
So I was going to come at it from the physicists' point of view to start with because it's very important for the physicists because there's so many things that they have to do in order to be able to interpret something that's been true in the data, that they have to trust what other people have done. And this is even more so when you have such big detectors as the LHC ones.	GridPP technical expert (based in the UK)	[trust] [PP history and culture]
And if you go into these big bang mode where it takes you two years to put this into production, particularly in a community which is as unstable as this is, as uncertain as this is, where changing the beam, which is something totally out of our control, can have implications everywhere, this is not the right policy. And you have to be much more agile in the trends in software engineering and agile in programming, and I am sure you know all about that. And here you do have to do that.	LCG technical expert (based at CERN)	[agility] [pragmatism]

Table 4. Example of quotations

Short cycle time system development”	**Compared to system development practices in our case**	**Organizational Implications**
Causes: Vague requirement Lack of experience Time pressure,	Yes. Vague requirements because it involves new technology and new experiments. Yes Yes Other causes: Faced with enormous uncertainties and environmental turbulence. Scale Existing culture of the particle physics community favours exploration, trial-and-error, and bricolage.	A collective attitude to deal with uncertainty and ambiguity; Capability of organizational learning; Capability to work under great pressure; Distributed management Drawing upon organizational memories
System development practices:		
Prototyping	Yes. “rapid prototyping” Result: documentation can’t catch up with the speed of changes.	Exploration, spontaneity
Release orientation	Yes, “fast development”, “nightly build” and “monthly release”	Incremental changes
Tailored methods	Yes, or no explicit use of methodology or methods.	Flexibility
Coding your way out	Yes, “hacking”	Pragmatism
Parallel development	Yes	Coordination, negotiation, persuasion
Fixed architecture	No. Driven by user requirements, which also evolve.	A common goal and shared vision
Components based development and use	Yes. Particularly necessary due to the distributed model.	Coordination
Tool dependence	Yes but mostly self-developed.	
Dependence on good people	Yes, very much so.	Democratic meritocracy, weak authority, high autonomy
Customer involvement	Yes. Power users use and test the system from very early on. The experiments develop applications to run on the Grid, with heavy interactions. Developers select power users as guinea pigs, and cultivate their user communities.	Learning, community building, informal communications
Maintenance ignored	No, but it is problematic.	
Quality is negotiable	Yes	“Aesthetics of imperfection”, pragmatism
	Other practices:	
	Parallel solutions competing against each other.	Federated structure

Table 5 Comparing characteristics of systems development practices with those of “short cycle time system development” presented by Baskerville and Pries-Heje (2004).

Individuality	**Collective Individuality**	**Collectivity**
- Intelligence - Autonomous - Freedom at work - Improvisation	*Community bonds among free-thinking individuals*	- Shared goal of physics - Emphasis on hanging out - Facilitative leadership - High level of trust - Hanging out
Anxiety	**Anxious Confidence**	**Confidence**
- Uncertainties - Unreliable software - Pressure from CERN and from users - Funding shortage	*Confidence as a capability to handle anxiety*	- Cleverness - "It will work" - History/organizational memory - Aesthetic of imperfection

Table 6 Paradoxes of belonging in GridPP

Unfolding	**Planned Agility**	**Planning**
- Adhocracy - Constant changes and adaptation - Exploration - Flux	*Planning to improvise; preparing for changes*	- Common goal/shared vision - Memorandum of Understanding - Deliverables - Milestones - Project map - Quarterly reports
Practices	**Structured Chaos**	**Structure**
- Bottom-up approach - Competition - Democratic discussions - Natural selection of parallel technical solutions - Transparency	*Providing minimal structure to support improvisation*	- Charismatic leadership - Collateral structure - Limited hierarchical command or authoritative management

Table 7 Paradoxes of organizing in GridPP

Environment/Present - Complexity of the Grid (multiple Grids, multiple groups of users) - Technological uncertainties - Time constraints (pressure of speed)	**Learned Improvisation** *Drawing upon past experience to handle uncertainties & complexities of the present*	**History/Culture** - Pragmatic approach - Computing expertise/successes in PP - Tradition of distributed collaboration in experiments
Spontaneity - Agility - Fast, incremental changes - Short cycle development - Trial and error	**Reflective Spontaneity** *Recovering meaning from actions retrospectively*	**Reflexivity/Learning** - Active informal face-to-face communication - Mailing lists, blogs, wiki, - Frequent multiple meetings, on site and virtual - Testing and monitoring

Table 8: Paradoxes of learning in GridPP

- Draw upon past experience to handle new tasks;
- Continuous reflection and learning;
- Extensive communications within and between different groups, with an emphasis on face-to-face informal communication;
- Work with power users; cultivate user communities;
- Project leader articulates clear vision and shared goals;
- Use high level milestones and deliverables to create momentum, but be ready to change them;
- Share knowledge by mailing lists, wiki, blogs, etc;
- Cultivate community bonding and shared identity;
- Develop trust, loyalty and mutual support;
- Motivate and rely on good people;
- Maintain high level of transparency within the project;
- Allow mistakes and unsuccessful explorations;
- Allow parallel solutions to compete with each other when resources permit; it might be a faster and safer way of achieving a goal.

Table 9. Key organizational practices in GridPP