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Toward a synthesis of complex adaptive systems and actor-network theory

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Abstract

In this paper we consider the commensurability of complex adaptive systems theory and actor-network theory to study co-evolutionary dynamics of IS emergence. We argue that the theories are defensible meta-theoretically when deployed from the philosophical position of critical realism. We provide a brief example drawn from a case study into the emergence of the phenomenon of research management at a research-intensive university. The paper concludes by summarising the benefits of this approach.

Keywords

co-evolution, complex adaptive systems, actor-network theory, critical realism.

INTRODUCTION

The phenomenon of IS and organisational change, in particular the theorising of its process and causality, has troubled IS researchers and practitioners since the field's inception. In theorising this dynamic, organisational change researchers seek either to understand the *what* of change by dividing implementation into *a priori* stages through which the organisation must be guided (Cooper & Zmud, 1990; Kwon & Zmud, 1987), or the *how and why* of change, by viewing implementation as a sequence of events that emerge over time (Orlikowski et al., 1996; Quattrone & Hopper, 2001). Others emphasise the diverse, vested interests of stakeholders and attempt to understand how order arises through negotiation, such as technology resistance models (Markus, 1983), IS evaluation (Wilson & Howcroft, 2005), or more broadly, studies of socio-technical systems (STS) that recognise the interdependence of social and technical systems of organisations (Kaghan & Bowker, 2001). In contrast, adaptation to complex problem scenarios can be conceptualised as a co-evolutionary environment where software systems, organisations, and individuals are each forced to adapt continually to the changing context wrought by one another's movements. When considering the role of information technology in organisational adaptation, there is a growing recognition of the contextual and mutually constitutive nature of IS on organisations and organisations on IS (Walsham, 1993; Boland, 1991). Recently Lee (2004) has called for a reformulation of an IS as being both the result of an information technology enabling an organisation and an organisation enabling an information technology. He notes that these mutually and iteratively transformational interactions can be expected to continue without end and therefore the result is not determinant but emergent (Lee, 2004).

There is a growing recognition (Kaghan & Bowker, 2001; Kim & Kaplan, 2006; Kim & Kaplan, 2010; Kim & Kaplan, 2005) that integrating the rationalist/functionalist perspective of complex adaptive systems theory (CAS) (Axelrod & Cohen, 2000) with the pragmatist/culturalist perspective of actor-network theory (ANT) (Law, 1992; Walsham, 1997; Callon, 2001) might yield fruitful insight into understanding the co-evolutionary dynamic of IS engagement. An integration of these theories holds promise for both the theory and practice of IS engagement; not only to inform studies of the sociology of technology and society, but also to help designers and managers of IS engagements negotiate the attendant complexities that they encounter. This paper seeks to address whether the co-use of these theories is defensible meta-theoretically. We consider the implications for commensurability of these theories when deployed from the philosophical position of critical realism. In order to demonstrate the applicability of these concepts, we draw an example from a larger case study undertaken to investigate how the phenomenon of research management emerges at a large research-intensive university that we shall refer to as the Australian State University (ASU). The paper concludes by summarising the benefits of this approach.

THEORETICAL BACKGROUND

Complex Adaptive Systems

An important starting point emphasised by complexity theorists is to counterpoint 'complexity' against 'complicated.' Complicated systems, although composed of many intricate parts, can be understood as the sum of these parts. This understanding underpins the classic reductionist, top-down, position that organisation studies have traditionally been built upon (Merali, 2004; Merali, 2006; Allen & Varga, 2006). Complex systems on the other hand comprise populations of interacting entities where the overall system behaviour is not predefined but rather emerges through the interactions of its entities. Complex systems are sensitive to initial conditions and characterised by open, non-linear dynamics. The study of complexity, therefore, takes a bottom-up approach, and in so doing dispenses with the default link between order and design (Merali, 2006).

Complex adaptive systems (CAS) theory is a branch of complexity research that focuses upon the dynamics of complex systems by unpacking the adaptive behaviour of interacting actors. Axelrod & Cohen (2000) define a CAS as a system composed of a population of agents, that we will refer to as actors, that seek to adapt. Actors, or populations of actors, interact with their environment and other actors within neighbourhoods, and employ a variety of context bound strategies that may be planned and purposeful or conditioned and reactive. Within the system a variety of performance measures exist to reinforce actors or strategies. These reinforcement mechanisms play an important role in steering the behaviour of actors; the design and application of criteria for success, coupled with the attribution of credit, creates an environment in which actors may choose to act in a manner that protects or maximises their perceived interests. Reinforcement mechanisms, however, do not operate within a static objective reality, but rather are interpreted to create an intersubjective-objective reality that is "reflexively related to actor's conceptions of their own interests" (Callon & Law, 1982).

Within such a framework, CAS theorists seek to understand how actors and/or strategies change over time creating variation, and how they become more or less common within a population (selection). Co-evolution occurs when actors are forced to adapt continually to the changing context wrought by others' strategies in order to remain relatively fit (van Valen, 1973). Unlike traditional evolutionary models that purely describe forces in terms of their impact upon a population (Van de Ven & Poole, 1995), CAS is also concerned with the intentionality and enactment of individual actors thereby incorporating elements of teleological motors of change. When considering teleological motors and intentionality, rationalist/functionalist approaches typically view Management as an "active" organisational brain that controls a "passive" organisational body, namely the human and non-human actors within the organisation, with the implicit assumption that managerial action is fundamentally adaptive and beneficial (Kaghan & Bowker, 2001). Intentionality, however, is not the sole domain of managers, and given that rights and resources are typically unequally conferred, and that actors may be subject to different reinforcement mechanisms the framework leaves room for conflict and power struggles. Therefore whilst CAS provides a useful lens to understand the motor of co-evolution (Kim & Kaplan, 2006), our understanding of the co-evolutionary dynamics is strengthened by incorporating a dialectic perspective such as actor-network theory to understand how order emerges in practice (Kim & Kaplan, 2010).

Actor-network theory

Actor-network theory (ANT) focuses upon the negotiations and trials of strength that are necessary to achieve partial blackboxing of new technologies and processes (Latour, 1987; Law, 1992; Walsham, 1997). It relies on the concept of socio-technical systems as a negotiated order constructed, tested and reproduced through action (Kaghan & Bowker, 2001), focusing on how it is that durability is achieved (Law, 1992). ANT theorists stress that closure of blackboxes is neither complete nor final (Latour, 1996) and require continued work to hold the divergent interests of allies in place thus demonstrating an interesting dimension of 'order'. Rather than merely being defined as a state or a pole, we see that order is an effect generated by heterogeneous means (Law, 1992) and that the "stabilisation of obdurate networks of human and non-human actants is an essential feature of all technological evolution" (Constant II, 2002, p. 1254). As noted by Latour "contrary to the claims of those who want to hold either the state of technology or that of society constant, it is possible to consider a path of an innovation in which all the actors co-evolve" (Latour, 1991, p. 117 italics in original). The applicability of ANT to IS studies has been the subject of increased attention over recent years (Walsham, 1997; Hanseth et al., 2004) and has been used to study the co-evolution of IS and organisations (Kim & Kaplan, 2005). Kim and Kaplan argue that by appreciating the multiple perspectives and inscribed traits of actors as well as the role of ambiguity in creating a body of allies, ANT provides valuable insight into understanding the form of co-evolution; order emerges in the form of blackboxes after socio-technical negotiations have been articulated, contested and resolved through processes of enrolment and translation of interests. It therefore provides an excellent lens to study co-evolution and emergence in practice.

An area where ANT is underdeveloped, however, is in its ability to conceptualise the drivers, or motor, of co-evolution. For example, ANT's concepts of enrolment and translation are analytical devices to understand

interaction and durability, but equally they are strategies employed by actors to accomplish their purposes. In dealing with actants symmetrically, intentionality is not only downplayed but viewed as another actant. For example, a PhD student might be conceptualised as a student (actant1) motivated by desire (actant2) writes a thesis (actant3) in the hope of receiving a PhD (collective goal of actant1+2+3). Yet ANT does not provide a mechanism to analyse how actors choose between alternative enrolment strategies, how these strategies might change over time. For example, unable to maintain the enrolment of actant2 motivated-by-desire, should the student replace actant3 write-a-thesis with actant4 reply-to-spam-PhD-email-offer? ANT also does not provide a mechanism to evaluate the efficacy of these choices. As a result, a vital component of any co-evolutionary narrative may lie unexplored when solely using ANT. This is not a criticism of ANT *per se*. Rather, it highlights an area in which our understanding of co-evolutionary dynamics might be strengthened by synthesising ANT with another theoretical framework such as complex adaptive systems theory.

META-THEORETICAL CONSIDERATIONS

In this section, we consider whether the proposed dual use of ANT and CAS is defensible meta-theoretically in other words, is their co-use ontologically, epistemologically, and methodologically defensible? The central tension that we encountered in attempting to rationalise the use of CAS with ANT arises from the manner in which ANT is typically deployed within the IS literature. Although ANT is not used consistently within a single philosophical position (indeed, many times a position is not articulated), the reference markers for its use within the IS field typically position the theory towards the Interpretivist/Constructivist pole. Conversely, theories in the field of complexity are typically positioned towards the Positivist/Realist pole.

One quick, and rather crude, solution would be to lean on the notion of a Pluralist Methodology (Mingers, 2001; 2008) and not just methodological pluralism. To summarise, Mingers argues that all research methods are merely instruments that provoke a response from the world. Paradigms are constructs of human thought in which incommensurability has been overstated. As a result we do not have to accept the integrity of paradigms, because their assumptions are always limited. Any research method, therefore, can be detached critically and knowledgably from its paradigm. Mingers concludes that research results will be more reliable if research methods, preferably from different paradigms, are routinely combined together. The appeal is undeniable; cast aside your anxieties and use any theory you wish. During an IFIP 8.2 Working Group panel (Myers et al., 2004), however, Walsham criticised Mingers's stance of pluralism arguing that methods are only commensurate within similar philosophical paradigms. Each paradigm is more than a construct of human thought but rather a belief system concerning the nature of, and our relationship to, reality. Indeed, the argument that a pluralist methodology will yield a more accurate, hence reliable, picture of a research phenomenon requires the assumption that there is a single independent, objective, reality. Such an assumption is antithetical to social constructivist approaches.

More recently, Walsham (2006) reaffirms the position that he adopted earlier (1993) that "interpretive methods of research start from the position that our knowledge of reality, including the domain of human action, is a social construction by human actors. Our theories concerning reality are ways of making sense of the world, and shared meanings are a form of intersubjectivity rather than objectivity" (p. 320). Nonetheless, it is interesting that he goes on to concede "…I am happy to accept the plausibility of the ontological position of the critical realist (Mingers, 2004) that there is an objective reality. Indeed, I see critical realism as one possible philosophical position underpinning interpretive research, along with others such as phenomenology and hermeneutics." We can maintain a belief in the existence of phenomena independent of our claims about them, without assuming that we can have unmediated contact with them and therefore know with certainty whether our knowledge is valid or invalid (Hammersley, 2002). Likewise, Mingers (2004; 2001; 2008) presents critical realism as "a way of resolving or dissolving most of the issues" associated with positivism, constructivism and postmodern positions, and "providing a consistent and coherent underpinning philosophy for information systems" (Mingers, 2004, p. 374). Critical realism aims to re-establish the realist view of *being* – that is, an independent objective reality – while acknowledging the constructivist view of *knowing* – that is, we can never have unmediated access with reality, but rather that our knowledge is mediated by our cultural assumptions and lived experience. It would seem that, whether or not one explicitly subscribes to the philosophical position of critical realism, reflexive researchers (Weber, 2003) would likely recognise parallels between the critical realist's epistemology and their practical experience of the conduct of research.

Or ignore meta-theoretical assumptions altogether?

As stated earlier, although ANT is not used consistently within a single philosophical position, its use within the IS field typically positions the theory towards the Interpretivist/Constructivist pole. Until recently (Latour, 2005), "Pandora's Hope" (Latour, 1999b) had been regarded as Latour's most complete articulation of the theory. In it, Latour refutes the entrenched position adopted by philosophers of science that scientific endeavour can be explained purely by social factors and social dimensions, arguing instead for the reintroduction of *reality* into science studies. Perhaps, fittingly, symmetry exists between this notion of reality emerging from circular

reference between the scientific object and the process of scientific enquiry and the circular arguments employed to present these claims. Whether it's a French trait, or just a coyness or dexterity on Latour's behalf that refuses to be pinned, labelled, and preserved like some butterfly in a philosophical taxonomy, it is infuriatingly difficult to position ANT definitively. Consider his use of the following terms: 'realistic realism' (Latour, 1999b, p. 15), 'constructivist realism' (p. 135), his practice of a 'realistic philosophy' (p. 111). The cynic may think this is little more than skilful theoretical evasion, but Latour uses these terms deliberately to highlight that the arguments between realism and relativism are misplaced.

In sidestepping the debate, Latour shows that rather than the Kantian view of knowledge – in which there is a gap between the world and language, between things in themselves and the transcendental ego, that must be reduced in order for correspondence to be achieved – the world, its representation and our understanding of it is a fluid process consisting of a chain of elements where matter is transformed into form. He demonstrates this in a number of ways, one of which is to follow an expedition of scientists to the Amazon to investigate whether the savannah is encroaching on the forest at Boa Vista, as would be expected because soil degrades from clay to sand, or whether a different dynamic is at play and the forest is actually advancing on the savannah. To answer this question, the forest undergoes a series of trials and transformations at the hands of the scientists: Cartesian coordinates from a map are transferred to the forest; soil samples are extracted, placed in to cardboard cubes, and systematically stored in an x by y wooden drawer; the samples are analysed for relative soil/clay content, and a colour code is assigned from a universal colour comparator; the textual comparator is graphed; and the graphic results are analysed and debated. From this process, we see that what is real and what is relative is actually linked on a continuum that is a chain of reference represented in the following figure.
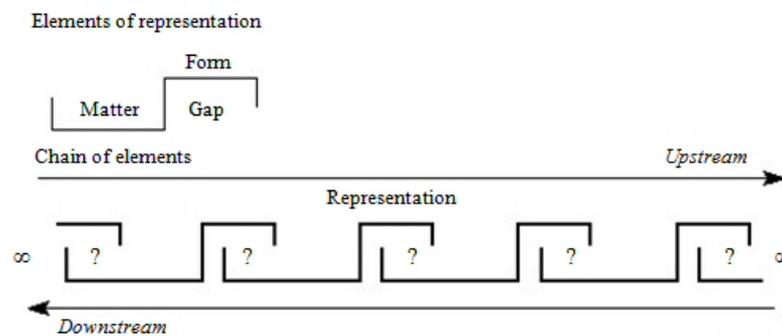

Figure 2.21 The "deambulatory" conception of reference follows a series of transformations, each of them implying a small gap between "form" and "matter"; reference, in this view, qualifies the movement back and forth as well as the quality of the transformation; the key point is that reference, in this model, grows from the center toward the two extremities.

Figure 1: Elements of representation (reproduced from Latour, 1999b)

Each element consists of matter and its representational form that is separated from the next stage "…by a gap that no resemblance could fill. The operators are linked in a series that *passes* across the difference between things and words, and redistributes these two obsolete fixtures of the philosophy of language: the earth becomes a cardboard cube, words become paper, colors become numbers, and so forth" (p. 69). Figure 2 views the chain of reference, represented as a cross section, from above. It demonstrates the trade-off between what is gained (amplification) and what is lost (reduction) at each information-producing stage. Each stage of transformation from the forest to the trip report lost locality, particularity, materiality, multiplicity, and continuity. At the same time, through the act of representation, calculation, standardisation, text, calculation, circulation and relative universality were gained. An essential property of this chain is that it must be reversible; it must be possible to travel in both directions. Otherwise, the chain ceases to "transport truth – ceases, that is, to produce, to construct, to trace, and to conduct it" (p. 69). Latour notes that "…by the end, inside the field report, we hold not only all of Boa Vista (to which we can return), but also the explanation of its dynamic." (p. 71) As opposed to the idea that a phenomenon exists at the meeting point between the inaccessible things-in-themselves, materiality, and categories of human understanding by the transcendental ego, phenomena emerge or circulate along the reversible chain of transformations. Furthermore, through the act of enrolment and translation, hybrids of human and non-human actants are blackboxed constituting a reality *independent* of the observer.
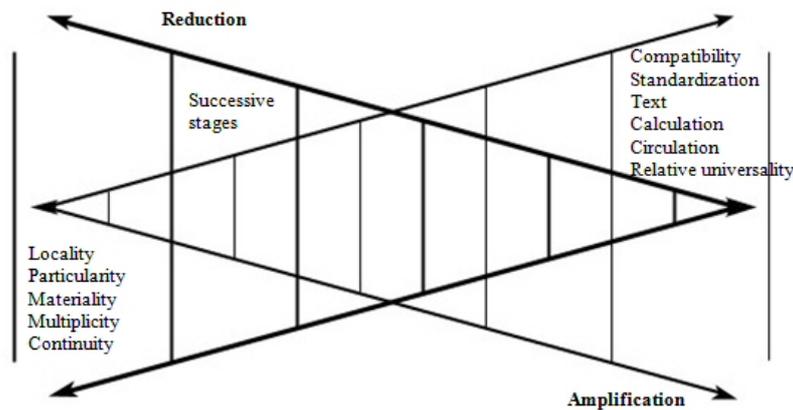
Figure 2.22 The transformation at each step of the reference (see Figure 2.21) may be pictured as a trade-off between what is gained (amplification) and what is lost (reduction) at each information-producing step.

Figure 2: Amplification versus reduction in transformation (reproduced from Latour, 1999b)

Commensurability of CAS and ANT approaches

It would be rash to attempt to discredit in this paper "the entire artefact of epistemology" (Latour, 1999b, p. 296) as well as the subject-object dichotomy of ontology as Latour implores. We note instead that ANT is often used from a phenomenological position that reinforces a constructivist epistemology and a life-world ontology (Walsham & Sahay, 1999; Hanseth et al., 2004). Given that much of the argument of Pandora's Hope was to re-establish the notion of reality and the process by which both it and our knowledge of it are constructed, we will consider how ANT and CAS are commensurable when deployed from the philosophy of critical realism.

First, CAS and ANT share a common theory of existence and reality, i.e., ontology, and the research object. Although the research object has qualities that exist independent to the researcher, nonetheless they are interpreted by the researcher. Of these qualities, the most notable is that the research object is in fact a network effect. As stated earlier, Merali (2006, p. 220) notes that the existence and persistence of a complex adaptive system is predicated upon the relationship of the system's actors to each other and the environment in continuous time. The emergent behaviour of a complex system, therefore, is in fact a *relational phenomenon*. The objects under investigation in a complex system are decentred phenomena that are at the same time composed of individuals but also relational, emergent behaviour. This is congruent with the ontological position of ANT's focus on the centred/decentred actor-network. Actor-networks are at once comprised of characteristics that are spatial, structural, and above all relational. Suffice to say it is pivotal to the co-use of ANT and CAS. Further, if we are to understand how emergent properties are produced we must be able to "access descriptions of the system at multiple scales from the micro to the macro *at the same time*" (Merali, 2006, p. 220 emphasis in original). By tracing the transformations of reference, as summarised by Latour in Figure 2, we find that we can move between the reductionary and amplifying stages. Theoretically then we have access to the global and the local at the same time without changing scale (Latour, 1999a, p. 18), even if this continuous unfolding of actor-networks can be difficult to achieve in practice at times (Mitev, 2009). Unlike Gidden's structuration theory, where phenomena exist as frames in the mind that are created and recreated, the resulting object that is blackboxed and punctualised exists externally to the mind of the participants. The research phenomenon emerges in the amplifying steps along its chain of transformations.

Second, CAS and ANT share a common theory of knowledge, i.e., epistemology. Whilst we argue for the existence of an objective reality and research phenomena, we recognise that our knowledge of it is always mediated by cultural assumptions and lived experience. Although the research object has qualities that exist independent to the researcher, nonetheless they are interpreted by the researcher. The existence of independent phenomena does not obligate researchers to formulate and evaluate models in order for CAS to be deployed successfully (Merali, 2006, p. 222). Indeed, any model inevitably raises questions as to the practicality of capturing the salient behaviour and rules as complex systems are open, non-deterministic systems that display weak cause-and-effect linkages (Pascale, 1999). We do not seek to develop and validate IS engagement models. Rather, we use the language and apparatus of CAS and ANT as explanatory, sense-making devices to interpret the phenomenon of IS engagement.

Third, CAS and ANT are commensurate when we consider the claims to truth that emerge from their accounts where the goal is to represent reality but not to reproduce reality (i.e. represent it on its own terms). It is recognised that it is possible to have multiple non-contradictory valid descriptions of the same phenomenon. In this paper we do not yet attempt to synthesise CAS and ANT into a new hybrid-theory, but rather to determine whether their combined application to IS engagement studies provides sufficient new insight into co-evolution

to warrant future work. The application of multiple theoretical perspectives to a single case is useful as a means of drawing out different facets of the case and better understanding the distinctive strengths of each theory (Mähring et al., 2004). The representation derived from CAS and ANT is always from a point of view which makes some features of the phenomena relevant and others irrelevant. For these reasons, therefore, there is no incommensurability with the concurrent use of ANT and CAS to study complex systems and IS emergence.

EXAMPLE

In order to demonstrate the applicability of these concepts, we draw upon an example from a larger case study undertaken to investigate how the phenomenon of research management emerges at a large research-intensive university that we shall call ASU. What we found is that no single system supports the research management endeavour. Instead, a socio-technical system exists that has not been designed. This socio-technical system is the outcome of (a) organic growth around localised academic self-interest with respect to academic promotion and funding, and (b) activity at each level (e.g., research group, school, faculty, and university) to maximise local-funding outcomes within a regulated environment.

The example that we will use is from the process of grant management and how this influences behaviour. From a CAS perspective, it would be natural to present an analysis based upon many interrelated agents (e.g., academics, administrators, and granting bodies) and expand upon the goal-seeking behaviour of academics as they act according to the rules/context imposed by other agents and their environment. It would be easy to say that 'ASU's research environment drives academics to compete for grants,' or 'Academics seek to win grants in order to maintain and improve their standing within the system.' We might formulate an equation in which promotion is attained by achieving some pre-determined threshold of grants, publications, and RHD completions. Failure to attain this threshold within a given time-period results in selection out of the environment. A state-based analysis by itself, however, does not describe the dynamics within the environment.

Instead, another way that we can 'get a handle on' dynamic behaviours, such as co-evolution and emergence, is by letting the analytical features of CAS temporarily recede from focus while simultaneously drawing ANT's concepts forward. Drawing on Latour's notion that a phenomenon and its representation emerge from a chain of transformations, we traced out the chains of transformation that enable research projects to emerge (summarised in Figure 3).
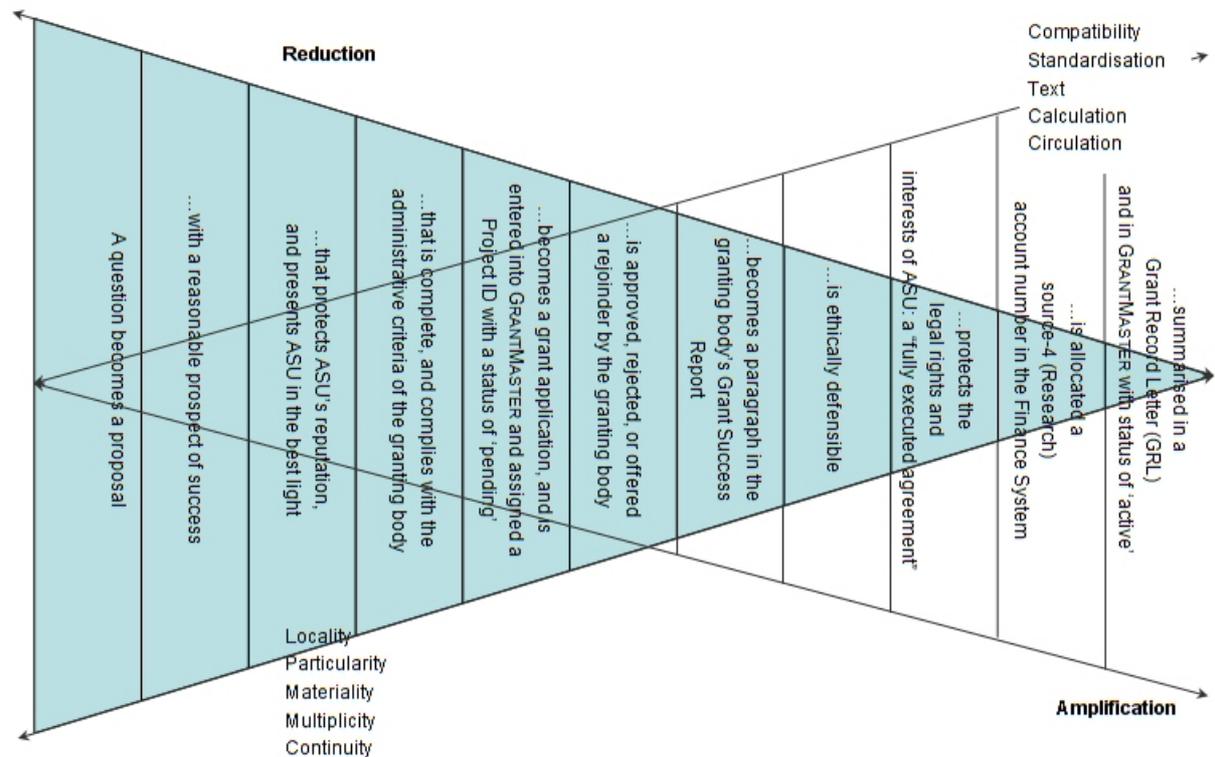

Figure 3: How a research project emerges

We found that diverse research agendas from all disciplines at ASU are standardised to emerge as account numbers and project identifiers that can circulate and be associated with an academic. We can traverse these transformations in both directions. Through reduction, we are led back to the local sites in which the project

was framed. We can see the particular lab, the particular whiteboard, and each actor that lent their material properties to strengthen the project. Here we see the multiplicity and diversity of research sites at ASU; we can physically circulate around the underground SCRAM-Jet facility, the reference libraries, and the laboratories. Through amplification, we are simultaneously led away from the particular toward the compatible and standardised. References to diverse research projects such as cancer vaccines, diabetes, and neurology become standardised to enable them to circulate among NHMRC panel experts as "informed filler texts" or among ethics committee members as ethics applications with standardised assessments of risks and impacts. Conversely, tracing the amplification transformations leads us toward a standardised, compatible representation that improves our ability to manipulate the phenomenon as it circulates in systems that permit calculation. As we continue to trace the amplification of these projects, we end up with all ASU's research efforts being represented as a sequence of numbers free to circulate within the Finance System, on the top of purchase requisition forms, on project acquittal statements, and curriculum vitas/achievement portfolios. We can see transformations and negotiations that enable a sequence of numbers to be an equally accurate representation of a research project as a tour of the laboratory and interview with the chief investigator. When manipulation is required at a point where a gap in the transformation occurs, it delivers insight into the adaptive moves, because new systems and processes emerge to create the bridges necessary to facilitate the manipulation.

At each stage of transformation, heterogeneous actors subject the project to trials and negotiations. It is only when all interests have been tied together, aligned, and blackboxed, that the project can be punctualised, rolled-up, and counted as a resource – a resource not only for the academic who can now pursue a research agenda, but also for the research group, the school, and ASU, which all benefit from the flow of secondary funding under the Federal Government's Institutional Grants Scheme.

Surprisingly, the winning of grants is neither the focal point of activity nor the goal of the grant management process. Rather, the ability to be associated with an account number is the goal of academics as it confers freedom and resources to pursue a research agenda. The translation of the research project into a Grant Record Letter and an active project identifier can be extended to demonstrate Latour's fourth meaning of technical mediation – i.e., crossing the boundary of signs and things as outlined in Figure 4 below.
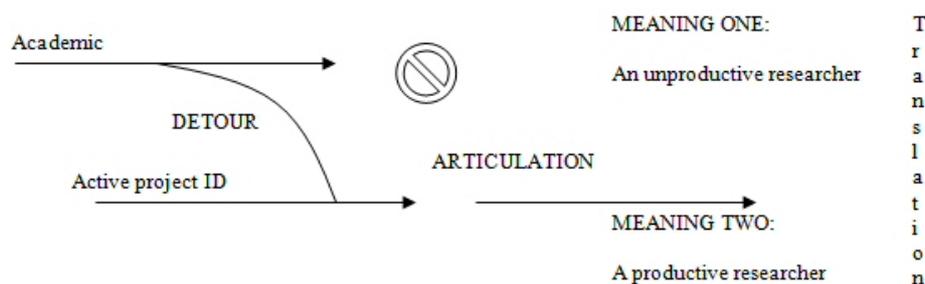

Figure 4: The change in meaning with an active Project ID association

Here the introduction of a second agent, the active project ID, into the path of the first, the academic, allows us to articulate a different meaning for the academic. An academic that circulates without an active project ID is viewed as an unsuccessful, or a research-inactive, academic. This academic is in danger of being analytically and literally selected out of the ASU environment. Alternatively, a translation in meaning occurs when an academic is associated with an active project ID. With a project ID, the academic becomes an academic with the freedom, conferred through resources, to pursue a research agenda. This academic is viewed as a productive researcher within the ASU environment.

Another way of conceptualising the change in meaning that arises from the association of project-IDs and account numbers is what CAS regards as the attachment of tags. These tags serve as signals to other actors, such that actors seek out others with whom to interact on the basis of similar or desirable tags. When these actors with mutually desirable tags interact a lot, new neighbourhoods form (Axelrod & Cohen, 2000, p. 95). We see this outcome when academic neighbourhoods coalesce around research interests such as symposia, conferences, and journals. Furthermore, the process of aggregating the performance of individuals up to organisation units strengthens the signal that is associated with the organisational unit. The relative strength of this signal serves to attract other academics and assists in the building of 'scale and focus' in research groups within schools and institutes.

This is the nub of the argument and demonstrates the rationale for the use of ANT alongside CAS. Rather than commence our analysis at the end-point by attributing causality to goal-seeking behaviour, we trace out the transformations necessary for specific phenomena to emerge. This analysis of grant management activities reveals the transformations that enable diverse research agendas from all disciplines at ASU to be standardised so that they emerge as account numbers and project identifiers that can circulate and be associated with an

academic. By following these transformations we discovered the translation in meaning that occurs when an academic becomes associated with a project identifier. The side-effect of tracing out the transformations, what we get for free in effect, is an understanding of how particular selection mechanisms for CAS emerge. We can demonstrate how calculation can occur within this environment to determine which academics are 'unproductive' and therefore in danger of being selected out of the ASU research environment. We also know which actors, both human and non-human, are active in making this determination of achievement. Furthermore, it is not merely a case of winning a grant but actually that there is an active association between the researcher and project identifier in GRANTMASTER and researcher and account number in the Finance System that will be measured and assessed. Given this translation in meaning for the academic, it is unsurprising that we then discover a range of strategies employed that attempted to increase control, short-circuit the amplifying transformations, and maximise resources, reputation, and esteem (unfortunately, it is beyond the scope to articulate them within this paper).

While academics would rarely think of the transformations to which their project proposal is subjected, the benefits of articulating these transformations is that it brings into relief the actors and negotiations and translations of meaning that may otherwise remain hidden. Where CAS deals with a state-based view of system and its dynamics – interaction, selection mechanisms, and adaptation – ANT provides the narrative on the transformations, thereby highlighting the surprise of action and how action can lead to unintended consequences.

SUMMARY – APPLYING CAS AND ANT TO STUDY IS ENGAGEMENT

Complexity theorists typically relate findings of spontaneous self-organisation in computer simulations to molecules, ecosystems, organisations, and even human agency. This is not to say that their insights are invalid, but in making such leaps from the physical to the social realm a number of questions are raised that are not readily answered (if indeed are answerable at all). Unlike traditional evolutionary models that describe forces purely in terms of their impact upon a population (Van de Ven & Poole, 1995), CAS is concerned with the intentionality and enactment of individual actors (Allen & Varga, 2006), thereby incorporating elements of teleological motors of change. By providing a lever into purposeful enactment in this way, CAS overcomes the tendency of ANT to imply but not address the goal-seeking behaviour of actors. CAS describes how actors interpret the selection mechanisms within their environment and modify their strategies to pursue what they regard as being within their interest. Actors reflexively interpret their environment and act according to what they perceive to be within their interests. When considering the question of motivation and goal-seeking behaviour of actors, it is not necessary to adopt a functionalist stance and attribute causality to the selection mechanism. Irrespective of whether selection mechanisms *drive* behaviour (that is, behaviour is modified in order to satisfy selection), or *steers* behaviour (that is, the mechanisms are interpreted), the application of selection will by definition reinforce the desired trait (because undesirable traits are removed over time).

A CAS analysis by itself, however, does not describe how selection mechanisms emerge in the first place or how they are applied. If we wish to understand the role of selection within socio-technical co-evolution, we must understand not only the criteria but the mechanism by which it emerges and the way that it is applied so we can understand how it changes over time. Using Latour's chains of transformation we can map how a phenomenon and its representation emerge. The chain of transformations can be traversed in both directions. Through reduction, we are led back to the local sites. Through amplification, we are simultaneously led away from the particular toward the compatible and standardised. The utility of tracing out the transformative stages is as follows. First, it reveals the role of actors at each particular stage that otherwise may have remained hidden due to the blackboxing of processes. Second, it reveals the negotiations performed at each stage (the mobilisation, autonomisation, alliances, and public representation activities). Third, it reveals the mechanisms by which the phenomenon emerges, circulates and becomes available to be attached as tags to actors. When we see how a phenomenon emerges, we can then understand how selection is made possible.

When considering teleological motors and intentionality, rationalist/functionalist approaches typically view Management as an "active" organisational brain that controls a "passive" organisational body (namely, the human and non-human actors within the organisation), with the implicit assumption that managerial action is fundamentally adaptive and beneficial (Kaghan & Bowker, 2001). Indeed, much managerial-induced episodic change, such as IS engagement, is driven from this perspective of enacting an envisioned end state. Intentionality, however, is not the sole domain of managers. Given that rights and resources are typically unequally conferred, and that actors may be subject to different reinforcement mechanisms, the framework leaves room for conflict and power struggles (Geels, 2004). While CAS provides a useful lens to understand the motor of co-evolution, therefore, our understanding of co-evolutionary dynamics is strengthened by incorporating a dialectic perspective such as actor-network theory to understand how ordering emerges in practice.

ANT provides the apparatus to analyse how interaction dynamics unfold. It enables us to generate a narrative on the transformations and their mechanics – through enrolment, translation, punctualisation, and blackboxing. ANT reveals how complex phenomena are constructed, aligned, emerge, and are sustained as actor-networks. In doing so, ANT overcomes CAS's state-based analysis by highlighting how transition between states, or alternate landscapes, actually occurs. When the complementary insights of each theory are overlaid it is hoped that we will gain a clearer picture of the co-evolutionary dynamic of IS engagement.

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