Coordination and Large-scale Complex Information Technology Systems: A Preliminary Literature Review and Exploration

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1 Introduction

This paper reviews issues surrounding coordination within large-scale complex information systems. It outlines issues and concerns in different academic areas, that roughly correspond to the disciplines of computer science, engineering, sociology, politics and economics. The review aims to provide an overview of the ways in which coordination is discussed across these different fields and disciplines. The idea is not to describe the methods themselves, but rather to highlight the assumptions that people working in those areas make about the ways in which coordination is achieved in large scale systems. It draws out the vastly different assumptions across these areas and how these partially relate to one another.

The paper begins with a review of coordination techniques in computer science and engineering, by focusing on agent-based models, equation based approaches, and control. This is followed by a review of organisational coordination and technological integration in the fields of sociology and politics, in terms of issues such as standardisation, boundaries, multiplicity, control and governance, social networks and small worlds. Finally, this paper reviews economic coordination between and within organisations by focusing on specific issues, namely transaction costs and techno-economic lock-in situations.

2 Method

Typically literature reviews focus on the available evidence about a specific topic. This literature review takes a slightly different approach, similar to the method used by social scientist Perri 6 (2004). Its purpose is to illuminate the different ways in which scholars from a range of academic disciplines believe that coordination is achieved in large-scale complex information systems.

The review was carried out by selectively searching for scholarly materials that is available in the European/ American-centred world. For practical reasons, these searches were confined to items published in English that were recorded in the following two databases: Cambridge Scientific Abstracts or EBSCO. The initial phases of the database search were designed to identify the bodies of literature that contained the key issues. Subsequently, limiting search parameters, such as date of publication and subject areas, were introduced to narrow findings, before manual scans of titles and abstracts were undertaken. For the logs of these preliminarily searches see appendix I on page 19.

The next step involved reading potentially relevant publications and trying to identify key issues and concerns that prevail in different academic domains. This was further explored by following up references, searching for additional authors and scanning articles by journals. The organisation of this paper was developed during the writing up process by grouping themes and topics, which were identified throughout the different contexts, on the basis of similarity of concepts and belonging to a particular academic discipline. The review was finalised in a sequence of drafts by incorporating further in-depth reviews of the identified scholarly materials.

3 Coordination through modelling and controlling

This section reviews common approaches in computer science and engineering that analyse the development and characteristics of large-scale complex information technology systems, which are an instance of a class of problems that tend to typical for systems. It outlines approaches that simulate the interaction of agents within systems with emergent properties and contrasts this to equation based descriptions that describe complexity within systems. This is followed by an outline of approaches where coordination tends to more an issue of control that is deeply entwined with concerns about information and its transformation within systems and their environment.

Agent-based models

Large-scale complex information technology systems, like other systems, are made up of many individual parts that interact with one another. An increase in scale of an information system often means an increase in interactions between individual parts. In computer science and engineering, the constituting parts of a system are often referred to as agents. This is particularly the case when such parts are understood as entities that function continuously and without constant guidance or intervention in an environment that is physical and at least partially unpredictable (Shoham, 1993)[1].

One of the main challenges computer scientists face is to represent agents and their behaviour and thereby investigate how they are coordinated. One way to represent the behaviour of agents within a system –which for instance could be an integrated information system– is a simulation modelling technique called agent-based modelling. Agent-based modelling is one approach to modelling situations where there is an absence of perfect scenarios, homogeneous agents, and long-term equilibrium[2]. Some have found it to be a valuable method for understanding repetitive interactions within a system of agents. It allows them to either specify the behaviour of agents through a normative model for developing a simpler and more descriptive heuristic model of behaviour, or to develop formal logic frameworks that reason about the behaviour of agents (Macal and North, 2006). Again, coordination in this form of modelling rests on the general premise that agents have a capacity to make independent decisions that relate to other agents within a system[3].

It is this "autonomy" of agents that implies the possibility of "infinite" configurations of the relations between agents, which makes agent-based modelling a suitable approach to capturing emergent phenomena. According to Bonabeau (2002), emergent phenomena result from the interactions of individual entities, which cannot be reduced to the system's parts, as 'the whole is more than the sum of its parts because of the interactions between the parts. An emergent phenomenon can have properties that are decoupled from the properties of the part.' (ibid. 7280) It is this characteristic that makes a system and its components difficult to understand and predict. This is particularly relevant for large-scale information systems, as the more interrelated agents within a system, the more like it is for phenomena to emerge that are beyond the individual components. Proponents of agent-based modelling, such as Bonabeau, argue that the produced representations of this kind of modelling approach are more natural to describe phenomena than to come up with equations that represent the emergent phenomena. Although Bonabeau (2002) concedes that equations

[1]For some computer scientists, agents are sometimes taken to have capacities for sensory input, motor control and are subject to time frames (Shoham, 1993), or may even possess natural language capabilities, whereas other commentators deliberately deny the centrality or even existence of such representation in agents (cf. Brooks, 1986; Agre and Chapman, 1987).

[2]According to Macal and North (2006), agent-based modelling is seen as offering distinct advantages to conventional simulation approaches, particularly in situations where there is (a) a natural representation as agents, (b) decisions and behaviours that can be defined discretely, (c) agents have a spatial component to their behaviours and interactions, as well as when there is (d) an emphasis on agents adapting and changing their behaviours, (e) learning and engaging in dynamic strategic behaviours, (f) when the past is no predictor of the future, or (g) when scaling-up to arbitrary levels is important.

[3]While some consider any type of independent component (e.g. software, model, individual) to be an agent (cf. Bonabeau, 2002), others –as Macal and North (2006) states– insist that a component's behaviour must be adaptive in order for it to be considered an agent. Others again (cf. Casti, 1997), argue that agents should contain both base-level rules for behaviour as well as a higher-level set of rules to change the rules.

can in principle represent any form of behaviour, the complexity of differential equations in so-called equation-based models increases exponentially as the complexity of emergent behaviour increases.

Equation-based models

Models based on mathematical equations are not subject to the significant practical issues that tend to constrain the agents-based modelling approach for large-scale system. Simulating the behaviour of all of the components within a system can be extremely computation intensive and therefore time consuming. Although computing power continues to increase, the high computational requirements remain a problem when it comes to modelling large-scale systems. Some practitioners and scientists in the field of engineering suggest that modelling some existing large-scale complex information systems would require computation time, with the current computation power, in the order of millennia if not exceeding the lifespan of the universe[4]. In this way, the formalism and the mathematics behind game theory have increasingly become significant in computer science as a method to deal with the stochasticity of agents' behaviour within complex dynamic systems. For example, the research on organisation and coordination within so-called multi-agent systems, by Messie and Jae (2005) introduces techniques from game theory to produce self-organising, polymorphic, lightweight, embedded agents for systems scheduling within a large-scale real-time systems environment. This approach facilitates optimum real-time scheduling through the emergent behaviour of thousands of agents, within a High Energy Physics experiment consisting of 2500 digital signal processors.

Although overcoming the practical problem of limited computational power through equation-based games tends to increase intractability, games are one way to deal with randomness or non-deterministicness in the interaction between agents. Another way to deal with these probabilistic elements that agents introduce in within a game –that may represents a complex system– is the deployment of Markov models. This form of analysis, based on a stochastic chain or a non-deterministic process with Markov property, is said to yield results for both the time dependent evolution of a system and the steady state of it. Heuristically, Markov chain theory, for instance, provides a model for analysing a collection of random set of variables, in contrast to other models, with a crucial aspect 'that it is forgetful of all but its immediate past.' (Meyn and Tweedie, 1993, 3) In other words, the conditional probability distribution of future states of the chain depends only upon the present state and is conditionally independent of past states. This, for example, would allow an application for systems engineering, that could understand the probability distribution of transitions that are determined by a variety of possible events, such as the failure or repair of an individual component within a system.

[4]For more information, see the discussion at LSCITS meeting with the practitioners of industries in November 2008 in Derby.

Such complexity of –for instance– an integrated information system could be represented in a state diagram, which represents the states and predictability of transition within a dynamic system. Such a diagram would consist of nodes that represent a possible state of the system, which is determined by the states of the individual components, connected by arrows that represent the rate at which the system operation transitions from one state to the other. In this way, Markov chains or processes can even be an integral part of agent-based model or game by introducing probabilities, as a way of dealing with a multitude of emergent properties.

Systems engineering

The question of emergent properties of a system leads to further challenges, for example the notion of coordination as an issue of control. For some computer scientists and engineers, particularly in the area of systems engineering, the question of emergent properties and their probabilities tends to be often phrased in terms of risks or control of dynamic complexity (cf. Calvano and John, 2004). One way of dealing with this, is to incorporate elements of coordination into information systems that would make the systems more agile in responding to the turbulence that characterises relevant environments, by allowing components to be dynamically added, modified, replaced and reconfigured. As Andrade and Fiadeiro (cf. 2002) suggest, this could be achieved through some form of coordination contracts that would places current requirements in line with future goals, while ignoring future specifications. Other authors in the field of computer science and systems engineering, promote systems that use goal interdependency information to perform plan optimisation and increase the value of the operation in terms of the objectives within a complex system. Again for others (cf. Malkhi and Reiter, 2000) the coordination of processes in large-scale distributed systems that have dynamic characterises is an issues of scalability and trust particularly in terms shared data abstractions.

The focus on control implies a further concern for data and its transformation within a system. Of course, information crudely spoken is always context dependent and can be seen as data belonging to or being related to a specific space. In other words, there must be something that specifies data for each context throughout a system. For instance, Barbuceanu et al. (1999) argue that systems engineering not only raises questions of practical operationalisation of models into programming tools, but also requires an understanding and modelling of the social laws that govern collective behaviour of multiple agents within a computational environment. Thus understanding the rules, regulations, conventions or laws of a particular space[5] (i.e. Euclidean or organisational) can enable a coexistence of multiple programs and programmers designing an information systems (Khunboa and Simon, 2001). Yet, it is these particular concerns about

[5]Similarly, commentators in the field of software engineering highlight the importance of mapping processes or so-called ontology building.

material and organisational arrangements that seems to retain the focus on controlling, as the notion of "wholeness[6]" – in terms of a system as emergent effect of it constituting components– that makes it extremely difficult to fix particular cases, to create certainty and trust. It is this balance between coordinating on one side the open-ended questions that introduce more (contestable) possibilities through emergent properties and on the other side to retain neatly conquered divisions that allow for coordination.

4 Organisational coordination and technological integration

This section reviews approaches in the social and political sciences. It outlines how standards can contribute to coordination and how this is complemented by and differs to other approaches that focus on coordination as an issue of ongoing practices that maintain interrelated components to be a part of a system. This is followed by an outline of notions of governance that perceive integrated information technology systems to facilitate better levels of control and questions whether other issues beyond a mere technological domain are considered to be significant in relations to governance and integrating information technology systems. Finally, this section discusses social networks and small worlds approaches and how they relate to coordination and large-scale information technology and how they differ from other approaches outlined in this review.

Standards and practices

Similar to many authors in the field of engineering and computer science, some social scientists are concerned about material and organisational arrangements that constitute systems. The processes surrounding the work of software engineers in establishing the specific characteristics of material and organisational arrangements, is seen by some authors in the social sciences as an instance of coordination work[7]. Randall et al. (2007), for example, argue that this type of coordination effort in engineering cooperative systems, it is a particular instance of work on classificatory systems and standards.

[6]The early twentieth century (re-invigoration of the) notion of a complex unity of systems, evident particularly in notions of living systems (e.g. brains composed of individual neurones, ant colonies, markets/ equilibrium price composed of individual traders, see for example Bullock and Cliff, 2004) treats holism and complexity as synonymous, by being based on all encompassing explanatory reduction. For more detailed discussion on different conceptions of complex wholes in the sciences see for example (see Kwa, 2002, 24).

[7]Authors in the field of health informatics suggest that the sharing of ontological models between different information systems, is a prerequisite for a semantic interoperability. Although some of these authors (cf. Pirnejad et al., 2008) hope that shared ontological models would be a basis to coordinate organisations by promoting alignment and integration of sets of practices, actors, and events, commentators (cf. Blobel, 2007) believe that the coordination health information systems is merely achieved through "creating" interoperability.

Within various approaches in the social science, particularly in an area called the social studies of science and technology, the emergence and effects of standards are considered an important area of investigation. In this way of thinking, information system are seen as being consequential; that means they are an effect of standardisations that might be different throughout different spaces or times[8]. This is particularly relevant for large-scale information systems, because the spacial and chronological distribution of its components (often just called objects for analytical purposes[9]) tends to be considerably greater. Authors such as Star and Griesemer (1999) and Bowker and Star (1999) suggest that objects which are indexed in standardised ways facilitate the coordination of heterogeneity that exists within a system. This form of coordination enables a system to respond to different combined agendas and aims that the complexity of the human, technical or organisational world may present. It removes local uncertainties through classificatory objects that exist across dispersed groups or entities. These so-called boundary objects are themselves supported and metaphorically held in place by other objects that are often not so rigidly fixed through standardisation or classification.

This may sound rather abstract but is has practical applications. For example, an integrated hospital information system could have the capacity to exchange information with another system for the purpose of monitoring a population's mortality. Classifying mortality with the aid of the *International Statistical Classification of Diseases and Related Health Problems* would be a way of coordinating information exchange between the two systems. However, the success of this particular way of classifying causes of death (despite a diversity of contradictory medical beliefs) is attributed to a whole range of broader factors, such as Westernisation, industrialisation, and bureaucratisation. Although these broader factors do not describe the details of adapting the ICD, it is this level of abstraction that facilitate its introduction in many different places throughout the world.

Other approaches within the social study of science and technology (and related areas) –rather than highlighting heterogeneity of objects that exist in different locations within a system– focus on the ongoing practices that contribute to the existence of such objects. Some of these authors (cf. Mol and Law, 1994; Mol, 1999, 2000, 2002) are interested in the practises of coordination that allow objects to maintain diversity and the ongoing adjustment work it may take to

[8]For example, in recent years, there has been a widespread believe that information technologies, such as the Internet, would strongly contribute to the democratisation of public life. While this might be case in Western Europe and North America, academics in communication and information such as Kluver and Banerjee (2005) argue that the reality of politics in Asia significantly modifies the findings of research that examine the political impact of information technology within North America and Western Europe.

[9]Some social scientists, particularly those who are interested in relationality, would not deploy the division between objects and subjects, or humans and non-humans, but instead generally for analytical purposes speak merely of objects which are in association to other objects. It crudely speaking surpasses issues of intentionality and retains a focus on relationality.

somehow align them within a particular system. To illustrate this further, a data set within an integrated information system can simultaneously contribute to a public health report or an individual patient record. For many of these authors, this raises the question of what kind of transformation work it takes to achieve this. Indeed, it is precisely because of the incredibly amount of effort that is necessary to integrate objects within a system (through endless processes of negotiations, refinement and reconfiguration) that more than often objects are rarely integrated in their entirety[10]. (E.g. a clinical information system is not public health information system; they may be linked). In contrast to holistic projects, the work by many of these authors highlights the *reciprocal* referenciality of independent material components. In this way the question of integration becomes an issues of partial connections. Things do somehow connect; disparate objects hang together in partial ways. Yet, it does not mean that there are indiscriminate sets of differences without links, traces and connections. Different object realities manifested by different material arrangements (e.g. two competing information system) at least bear the *possibility* of being mutually adjusted (e.g. in form of an integrated system).

Governance and integrated systems

For some social scientists, the issues of standards and the way they may undermine or contribute to the making of objects within a system raises a set of political questions. Mol (2002), an empirical philosopher, generally asks to consider the effects of specific material relations that are outcome of aligning of coordinating. In other words, what would be at stake if conditions of possibilities fail or succeed to materialise? Yet, in contrast to these ethical issues, some political scientists emphasis more on issues of control or governance. For example, political scientists in the field of public administration/ management argue that coordination between different governmental organisations for controlling extreme events, requires to build on the human ability to learn and adapt to new information, which in turn can be supported by an appropriate information infrastructure (cf. Comfort and Kapucu, 2006). Similarly, research on child welfare in the US (by a coalition of private and public agencies) has indicated that an integrated child welfare and juvenile justice system promises to increase well-being and reduces levels of abuse and neglect (Wiig and Tuell, 1996). Among the five phases to achieve this integration, data collection and information sharing is one crucial issue. In Wiig and Tuell's proposed framework, data are seen as the foundation for integration and coordination. Information sharing is seen as helping to coordinate multiple services, improve case management, and identify those at risk (Slayton, 2000). The capacity to share information among these

[10] It took more than five decades for the ICD to be adopted by the World Health Organisation and another 19 years for WHO to stipulate the use of the ICD in its most current revision for mortality and morbidity statistics by all Member States. The coming into use of the tenth version of the ICD took almost four years from the time it was was endorsed by the forty-third World Health Assembly in May 1990.

agencies is suggested to relate to the development of an integrated information sharing system. System development, in addition to focusing on the system's aims of collaboration and sharing, is suggested to closely focus on confidentially law and practices, as well as range of other control features such as outcome and process measurements.

Changes in public organisations, particularly attempts to integrate government structure, has always been a quest for practitioners of government (Jennings and Crane, 1994). Yet, this raises issues of the relation between coordinating public organisations and introducing information systems, particularly systems that tend to be fairly large or integrated. According to social scientist, Perri 6 coordination is a strategy, where integration is the operational aspect of coordination. This has been evident in the attempts to integrate information systems of public organisations, as a part of a so-called joined-up government imitative in the United Kingdom, in line with many reform projects that emerged in English speaking countries from the end of 1980s onwards. Yet, publications from the independent research institute called Demos complement and contrast the notion of joined-up government with that of holistic holistic government (Perri 6 1997; Perri 6 et al. 1999). While joined-up government refers to the consistency between the organisational arrangements that may enable to work together, holistic government entails mutually reinforcing sets of objects. In other words, the holistic notion of objectives that frame outcomes, allows for identifying ways to achieve them. To put it even more sharply, the distinction drawn by Perri 6 and others, shows the entwined aspects of operational and strategic work that needs to be considered when attempting to understand integrated information system[11].

Despite an absence of concrete empirical evidence, integrated information technology has become a key component of a so-called transformational government initiative that has replaced the policy rhetoric of jointed-up government in the United Kingdom (see Cabinet Office, 2005). Some political scientists commenting on debates in public administration/ management, argue that the wave of public sector reforms that focused on economic efficiency and effectiveness since the 1980s, have been replaced by a new form of governance arrangements around the year 2000. Political scientists such as Dunleavy et al. (2006) suggest that the so-called concept of digital era governance adequately describes arrangements that not only reintroduce government control in many areas and reorganise government around distinct client groups, but also fully utilise the potential of digital storage and current information communication technologies to transform governance. Such attempts of transforming governance arrangements are even mirrored in international research conducted in the field of computer science. Su (2005), for example, sees the need for integrated transna-

[11] Studies in organisational culture point to the way artifacts as a manifesting of organisational process and structure relate to espoused values (in form of objects strategies), which in turn relate to basic underlying assumption. See for example Schein (1992). Presumably, attempting to change one part such as artifacts, always requires solid consideration for the other interrelated elements such as organisational values in light of their basic assumption.

tional information systems for solving global problems (e.g. disease detection and control, terrorism, immigration and border control, and illicit drug trafficking) that would allow sharing and coordinating information and collaboration among government agencies within a country and across national borders[12]. For other commentators (cf. Shabo, 2006) in the field of healthcare informatics, a key issues for coordinating integrated information systems is the tension between those who produce or use information on one side and those who keep or control information on the other side[13].

Social Networks and Small Worlds

There is an established sub-field in sociology that focuses on the nature of the *relationships* between people, and views these relationships as network-like in nature[14]. Although the graph-based representation of this analysis can neither shed light on the motivations behind interactions between people, nor can it specify their organisational context, it can identify key relationships that are not captured by any conventional organisation diagram. Since the publication of Watts and Strogatz's work on *Collective dynamics of 'small-world' networks* in 1998, a large number of research has been published on the quantitative properties of large scale networks in the physical, biological and social sciences. However, only a small number of studies of the ways in which large scale information technology networks are used – that is, analyses of the *patterns of use* of the networks, not the network topologies – have been reported in the literature. The reports suggest that the patterns of use of information technology networks exhibit the characteristics of small world networks, i.e. highly locally clustered graphs with short average path lengths.

Within the literature in this area two types of observation can be made. First, both social network analysis and small world methods assume that coordination is achieved through the forging of social relationships of one kind or another. Some researchers interested in small worlds further hypothesise that the growth of large networks is usefully understood in terms of phenomena such as preferential attachment—i.e. the tendency of new members of a network to link preferentially to members who already have a relatively large number of links, rather than to those with few links. In other words, stable large scale social structures can be understood as a product of the ways in which individuals join existing networks. The second observation is that this way of thinking about networks and network growth provides useful points of comparison and contrast

[12] Su (2005) describes a prototype of an integrated transnational information system between the US and two Latin American countries.

[13] Shabo (2006) advocates independent health records banks, which are regulated, where patients control access rights. Although Shabo acknowledges that such concept would require a radical preemptive legislation and highly depends on international standards, it would have a potential for completeness and ensuring privacy.

[14] For example, a number of studies on the use of email within organisations have shown who emails whom within an organisation, and reveal myriad organisational relationships (cf. Cole et al., 2005).

to other bodies of literature discussed in this review. For example, there is a marked contrast with the agent-based approaches discussed in section 3 on page 2ff. Put at its simplest, agent-based modelling approaches tend to assume that network properties emerge from the interactions of autonomous agents, and that stable network behaviour –where it temporarily exists– is a product of repeated dynamic interactions between agents. Network analysts, in contrast, assume that networks are the natural order of things. All social interactions occur in a wider social context, and this context constrains the behaviour of individual agents in the network.

A similar point can be made about the other two bodies of literature discussed in this section, which are both concerned with the relational nature of coordination. In contrast to agent-based modelling approaches, the literature on governance in the area of politics start from the assumption that network-like arrangements are the natural order of things. However, like assumptions of agent-based modelling approaches, the literature of the social studies of science and technology (particularly those streams in the tradition of the sociology of translation) tends to treat network-like arrangements as emergent effects of the relational interaction of its individual material components.

5 Economic coordination and large-scale information technologies

Many economists are interested in information technologies. Some are interested in the economics of information—for example how information can affect behaviour, perhaps most obvious in the ways in which information (e.g. rumours) can affect stock markets. Others are interested in the economics of networks, where information technologies are an example of networks that can be studied empirically. Yet other economists are interested in innovation. For them, information technologies are both an example of technological innovation (i.e. individual components are combined in novel ways to create new products) and a cause of innovation in organisations (i.e. they change the economics of organisational processes). As in earlier sections selected key issues and ideas are discussed here, which are illustrative of the ways in which economists approach coordination and large-scale information technologies.

Transaction costs

In the last thirty years, a branch of economics has focused on transaction costs. As the name suggests these are the costs associated with any transaction, whether it occurs in a market (e.g. buying a gadget on eBay) or within an organisation, where for instance two parts of a firm collaborating in an R&D activity. As every transaction involves some cost, economists of course have become very interested in large scale information technology systems, and in particular in the Internet, because they have a marked effect on transaction costs. It might be easier to buy a book on Amazon than go to a shop, and an economist would argue that people tend to favour Amazon because their own costs –both the cost of the product itself, and the time costs of finding a copy– are lower. This is one instance where evidence strongly suggests: Amazon, eBay and other services have changed the structures of the markets they operate in.

Typically, studies in information systems assumed that information technology networks have positive effects on market transactions. For example, Malone et al. (1987) argue that networks reduce transaction costs because they allows information to be communicated in real-time, at lower cost than through other means, thereby reducing the cost of obtaining that information. Others (cf. Benjamin and Wigand, 1995) discuss how these technologies can reduce transaction costs by decreasing coordination costs within the 'value chain'[15], resulting in benefits for consumers through lower prices. Yet others (cf. Ciborra, 1993; Brynjolfsson et al., 1994) argue that the use of information technology increases the conditions under which the market mechanism is an efficient allocative structure, i.e. brings buyers and sellers together efficiently. Moreover, these authors such as argue that information technologies can reduce the effect of opportunistic conduct by increasing the possibility of monitoring behaviour in partnerships and increase the strategic deployment of linkages and networks among cooperating firms intending to achieve joint strategic goals to gain competitive advantage.

In contrast to the above authors, Cordella suggests that 'it is possible to identify situations where rather than reducing transaction costs, ICT will increase them.' (ibid. 2006, 196) Building on transaction cost theory and notions of information technology, he highlights the importance of considering the interdependency of factors that contribute to transaction costs when these technologies aim to reduce the effects of transaction costs. One example here might be shared electronic clinical records: it tends to cheaper to maintain records in separate sites such as a GP surgery and hospital, rather than share data, because the cost of developing the necessary infrastructure is very high. Cordella reminds us that, like shares, transaction costs can go both up and down when information technology networks are introduced[16].

Techno-economic lock-in

Drawing on Schumpeter's *Theory of Economic Development* (originally published in English in 1934), Varian et al. (2004) and other economists argue that

[15] Concept of value chain has been severely criticised in the economics literature.

[16] Already decades ago Schultze and Vandenbosch (1998) addressed the problem of information overload and point to the negative effects of information technology due to greater levels of complexity being aced as a consequence of the increased quantity of information made available through information technologies.

information technologies are an instance of "combinatorial innovations". In contrast to previous technologies (e.g. petrol engines or micro-electronics) that took over a century or at least decades to mature, current large-scale information technologies such as the Internet reached a point, within few years, where both companies and end users are able to combine components in new ways. Developers sharing tools and protocols can produce innovation products very rapidly. A good example of this form of loosely coupled community of programmers, with no centralised direction or authority, is the open source community developing and maintaining the GNU/ Linux operating system, where combinable inventions are particularly prominent as codes are open to scrutiny and analysis.

Varian et al. (2004) also argue that information technologies have measurable effects in markets, for example allowing the personalisation of pricing and the bundling of otherwise distinct products together in a single sale (what economists call economies of scope). Other authors argue that the entire nature of information in organisations and in markets has been changed by large scale networks. For example, Elsner (2004) suggests that information increasingly displays the features of a collective good –roughly, something that everyone can access and share– because large-scale information technologies make information so widely available. Indeed, the suggested abundance of information bears little resemblance to the conventional economic assumption of scarcity (i.e. most resources such as oil and metals will eventually run out). Yet, simultaneously, economists such as Elsner points out, there may also be an artificial construction of scarcity on the Internet where the behaviour of some firms, 'is increasingly at odds with technological reality' (Gallaway and Kinnear, 2002, 446; cited in Elsner, 2004, 1034).

Varian et al. (2004) suggest that information technology tends to be susceptible to 'lock-in'. Lock-in refers to the situation where the value of a good depends on its compatibility within a network, where goods are required to be used in conjunction with others (ibid.). Even though the Internet is characterised by ease of combining components, through shared tools and protocols, the cost of switching from one service or product to another might outweigh the value of using it. For example, if an organisation has been using a commercial solution for its human resource management for some years, the costs —in money, and disruption– of switching may be too high, even when existing solution are deemed inadequate. Yet, this is even more relevant for large-scale information technology, as initial investments tend to considerably greater. Granovetter and McGuire's (1998) analysis of the history of electricity in the United States illustrates how adopted technologies became increasingly irreversible in economic terms as networks expanded.

Some authors, in the area of socio-economics, suggest that well established lock-in situations create the potential for alternatives to emerge. According to Callon and Rabeharisoa (2008), lock-in situations for economic agents (e.g. developers, producers, distributors, and consumers) can create a basis for the likely emergence of concerned groups that 'decide to embark on investigations that will enable them to explore new options, to define more clearly the problems facing them, and to seek possible solutions.' (ibid. 246) For example, the Free Software Foundation (partially behind the GNU/ Linux OS) gained its momentum and intensified in response to MIT licensing code created in its Artificial Intelligence Laboratory to a commercial firm (cf. von Krogh and von Hippel, 2003). However, other authors are more concerned about how large-scale information technologies could facilitate new organisational forms in a global economy (e.g. hub-and-spoke clusters and networks) and the public policy approach this requires (cf. Elsner, 2004).

6 Conclusions

This paper has reviewed issues surrounding coordination in integrated or large-scale complex information system. It has provided an overview of key issues across a range of academic fields and disciplines. It has outlined how agent-based models and equation based approaches differ from each other and the advantages and limitations both have as a way of coordinating complex or large scale systems. It also established how the concern of emergent properties within these two approaches contrast with the concern for control in systems engineering. This was followed by a review of organisational coordination and technological integration that showed how standardisation is a key issue when dealing with ontological diversity and concern the resultant multiplicity raises. It also established how this differs form the issues of organisational control and governance which have changed over time. It then discussed social networks and small worlds approaches and how they relate to coordination and large-scale information technology networks. This was compared to assumptions that underline agent-based models, where only some social scientists view networks as an emergent effect of its interacting parts. Finally, this paper reviewed economic coordination between and within organisations, by focusing on transaction costs and techno-economic lock-in situations.

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