

EPSRC GRANT GR/MO2590/01 - REVIEW RERORT

IMPLICATIONS OF THE THEORIES OF COMPLEXITY FOR THE CO-EVOLUTION OF THE BUSINESS PROCESS & INFORMATION SYSTEMS DEVELOPMENT

BACKGROUND/CONTEXT

The concise name of the project is the '*Legacy Systems Project*'. There are two elements to the background, one is the legacy issue and the other is the development of the study of 'complexity'; both will be summarised in this section.

The LSE project is one of 28 projects in several UK Universities, funded by the EPSRC, under the Systems Engineering for Business Process Change (SEBPC) Programme. This is the second award under this Programme made to the LSE Complexity Group. The first was for a one-year preliminary study, which helped to identify the business partners and the specific research questions for the current three-year study, which started in October 1998. The importance of the LSE project is that it focussed on the *relationship* between the changing business process and information systems development, when most of the other 28 projects concentrated either on the evolution of technology from a software engineering or computer science perspective or on the business aspect. Its other main contribution is that it used complexity as the theoretical framework (a) for the study of that relationship; (b) to gain an understanding of the nature of change in organisations; (c) the development of a methodology; and (d) the exploration of models. In addition, the project provided a practical application to test the developing theory of complex social systems.

The Legacy Issue [*The Bibliography is at Appendix 1*]

The definition of a legacy system has changed over time and the literature has shown a progression from addressing only the technical perspective to encompassing the wider socio-technical issues of legacy. Within the software engineering literature the focus is technical and the systems are described as old and large, written in assembly, or an early version of a third generation language. They have been developed 20-30 years ago without anticipating that they would be still running decades later. Reengineering, reverse engineering, freeze and encapsulate, and software-reengineering patterns have been suggested as viable solutions to the legacy systems' problem. [Adolph 96, Bennett 95, Chikofsky & Cross 90, Pooley & Stevens 98, Sneed 95]

The systems were developed with technology that proved inflexible and unable to accommodate change, while Lehman [Warren 99] has argued that software be designed to evolve and software systems have changed extensively over time to accommodate changes in their environment. However, years of changing and adding-on has resulted in improved functionality, but also in increased complexity coupled with inadequate documentation, resulting in poor system understanding. Moreover, these systems are associated with high maintenance costs [Bennett 95] and they have become very difficult and expensive to change to further support the business objectives.

The business perspective defines legacy as “*large software systems that we don’t know how to cope with but that are vital to our organisation*” [Warren 99]. In addition, it is suggested that the problem of legacy should not be regarded as technological deficiency but rather as the result of management’s poor understanding and inaction. Ransom et al [1997] developed a method for assessing legacy systems for evolution by incorporating changes as a core activity of the software life cycle, and not as an extension to it. The legacy problem has also been seen as a misalignment between the strategic vision of the current business and the old business model embodied in the legacy system and that these systems have become a constraint in business process redesign [Gibson et al 98; Light & Holland 98].

More recently, legacy systems have come to be regarded as socio-technical systems containing legacy software [Gold 98]. When the balance between the technical and business dimension is lost, legacy can be seen as a *gap* between the business needs and the technical capabilities [Ramage & Munro, 99]. Although the system is performing crucial work for the organisation, and represents years of accumulated experience and knowledge, it can no longer support the business and its future direction. According to this wider view of legacy, a framework was developed [Brooke et al 98] based on the dynamic interrelationship between organisational and technical dynamic processes. Finally, an ethnographic approach to research suggests, “*legacy concerns are not merely technological in focus but also organisational in the sense of being intimately wrapped up in the everyday accomplishment of work*”. [Randall et al. 98]

Although the early definitions and perspectives of legacy systems have focused mainly on technology (software engineering), they have progressively come to encompass the business, organisational and human context, which support the findings of the current project. Legacy is a multifaceted issue and its many facets are interdependent and interrelated. Furthermore, understanding the organisational and cultural conditions that facilitate the co-evolution between IS development and the changing business process may lead to a better understanding and to an amelioration of the problem.

Complexity

There is as yet no single theory of complexity, but work in the past four decades in physics, chemistry, evolutionary biology, mathematics and computer simulations, have contributed to an understanding of the behaviour of complex systems. The project drew on work on *complex adaptive systems* (CAS) [Gell Mann 94, 95/6; Goodwin 95, 97; Holland 95, 98; Kampis 91; Kauffman 93, 95, 00; Lewin 93; Mainzer 96; Waldrop 92; Webster & Goodwin 96], *dissipative structures* [Prigogine 90; Prigogine & Stengers 85; Nicolis & Prigogine 1989; Nicolis 94], *chaos theory* [Gleick 87], *autopoiesis* [Maturana & Varella 92; Luhman 90], and *increasing returns* [Arthur 90, 95]. Also on work on complexity and *economics* [Hodgson 93] and *management* [Lane & Maxfield 97; Parker 95; Parker & Stacey 94; Stacey 95, 96, 00, 01] The work of the LSE Complexity Group has focused on complex *social* systems, and specifically on human systems and organisations. It does not map directly from any of the sciences, but uses the generic characteristics common to all complex systems as a starting point, and then considers what is relevant and appropriate to human systems. [Mitleton-Kelly 97, 98, 00, 02; Mitleton-Kelly & Papaefthimiou 00, 01]

Co-evolution, in the context of the research project, is taken to mean that *the evolution of one domain is partially dependent on the evolution of the other* [Ehrlich & Raven 1964; Futuyama 79; Kauffman 1993 & 1995, Koza et al 1998; Maruyama 63; McKelvey 1999a & b; Pianka 1994], or that *one domain changes in the context of the other*. Or as Kauffman describes it “*Co-evolution is a game of coupled deforming landscapes.*” [Kauffman 1995; Kauffman & Macready 1995] The notion of co-evolution places the emphasis on the *evolution of*

interactions and in human systems, co-evolution refers to the relationship between the co-evolving entities. Furthermore, co-evolution, can only take place within an ecosystem [Kauffman 1993] and can occur at all scales, thus affecting both individuals and systems. An ecosystem in biology means, “*each kind of organism has, as parts of its environment, other organisms of the same kind and of different kinds*”. [Kauffman 1993 p242] In the organisational context of the project, a social ecosystem means all related socio-cultural and technical entities within an organisation, as well as related organisations within an economic context, which have an influence upon and are influenced by the organisation under study. One way of thinking about co-evolution within an ecosystem is in terms of related fitness landscapes. “*Due to landscape deformations as species co-evolve, an adaptive move by one species can cause the fitness of other species to decrease.*” [Kauffman 2000]. Adaptation by one entity alters the fitness as well as the fitness landscape of related entities at all scales. (The term *entity* is used as a generic term, which can apply at different scales to individuals, teams, organisations, industries, economies, etc). The project has helped us to understand the process of co-evolution: it is often easier to observe co-evolution as adaptation or co-adaptation of related entities in the short-term, and as co-evolution in the longer-term through a process of reciprocal influence and feedback.

In an organisational context, complexity provides an explanatory framework of *inter-relationships*: of how individuals and organisations interact, relate and evolve within a larger social ecosystem. Complexity also explains why interventions may have un-anticipated consequences. The intricate inter-relationships of elements within a complex system give rise to multiple chains of dependencies. Change happens in the context of this intricate intertwining at all scales. We become aware of change only when a different pattern becomes discernible. But before change at a macro level can be *seen*, it is taking place at many micro-levels simultaneously. Hence *micro-agent interaction and change leads to macro system evolution*. This is a key insight, provided by the project, on how organisations change over time.

KEY ADVANCES

The two Legacy Systems projects (1-year preliminary study & 3-year project) in conjunction with one other 2-year EPSRC funded project with the Aerospace industry, Warwick and Cranfield Universities (GR/M23175/01) have made it possible to explore the **generic characteristics of complex adaptive systems** and to contribute to the development of a **theory of complex social systems**. [Mitleton-Kelly 97, 98, 00, 02; Mitleton-Kelly & Papaefthimiou 00, 01] In that process the principle of *co-evolution* as well as the following principles have been explored in depth: *feedback, far-from-equilibrium, emergence, connectivity, inter-dependence, historicity, self-organisation, exploration-of-the-space-of-possibilities, increasing returns and creation of new order*.

The three EPSRC projects have also helped to develop a **methodology**, using the principles of complexity both as the theoretical framework and as a method of analysis. This methodology is being used in a fourth EPSRC funded project known as ICoSS (**I**ntegration of **C**omplex **S**ocial **S**ystems) (GR/R37753: Enabling the Integration of Diverse Socio-Cultural and Technical Systems Within a Turbulent Social Ecosystem), which started in September 2001. **Modelling techniques** such as the NK model used by Kauffman [93, 95, 00] and Levinthal [97; Levinthal & March 81] to look at co-evolving entities, and agent-based modelling [Axelrod 90, 97; Axelrod & Cohen 00; Bonabeau et al 99; Casti 97; Epstein & Axtel 96; Ferber 99] were explored. Agent-based models and simulations will be used in the new ICoSS project.

Findings from the Legacy project include the identification of **enabling and inhibiting conditions** which can facilitate co-evolution between information systems development and the changing business process; the notion that **legacy** is not just a technical but a **socio-cultural issue** and the interdependencies between these factors; identification of the **business, organisational and technical factors** that contribute to legacy; that legacy systems are not just a problem but may also be seen as **inherited assets**; a deeper understanding of the **nature of change** and of **organisations as complex evolving systems**.

RESEARCH METHODOLOGY

A case study research approach [Benbasat et al 87, Yin 94] was used based on semi-structured interviews, using a set of topics not a questionnaire. Two case studies were used to look at the relationship between information systems development and the changing business process, with an international bank at their New York and London sites and with a UK Building Society. A third case with the Humberside TEC (Training and Enterprise Council) using a combined ethnographic approach with semi-structured interviews, focused on the evolution of the organisation and the difference made when complexity-thinking was adopted. A fourth study with BT focused on culture and complexity. In the three case studies considerable time was spent with each organisation over a 2-3 year period, understanding their ways of working and relating; studying the process of change; and contributing to their understanding of complexity. In addition, the main contact person in the Bank published a book on complexity and the PI is credited in the acknowledgements.

The interviews were recorded subject to the permission of the interviewee, to capture the specific language used, technical expressions, etc., as well as the details and richness of the narrative. The recorded material was transcribed and used in conjunction with the audiotapes (to enable the researcher to experience the spoken narrative, when she had not been present at the interview) for the analysis. The interviews and other research material were treated as confidential and only accessible to the researchers, and the resulting reports were non-attributable (individual interviewees were not named). All material was submitted to the companies used as case studies for clearance before publication. In addition, there were workshops, meetings and long informal conversations with individuals and groups in the four organisations.

Two types of analysis were used: a qualitative approach to identify the relevant socio-cultural and technical elements and a quantitative approach to model the relationships using the NK model.

The **deliverables** from the project were 18 conference/seminar papers, a Radio 4 interview and 4 chapters in 3 books. In addition there were individual reports to the two organisations involved in the case studies and presentations to the Bank in New York. The deliverable from the interviews of the third case study with the Humberside TEC was a multi-perspective narrative using the voice of the interviewees to describe the process of change in the Humberside TEC over a 5-6 year period and how that change was impacted by complexity-thinking. This case is now being widely disseminated and used for further study. In addition, the TEC run a 'Complexity Club' for its business members; it directly and indirectly influenced the organisations within its geographical area of operations.

The fourth study with BT on Culture and Complexity was based on a series of workshops and meetings to understand the notion of culture; what it meant in the BT context; and what were the implications if a complexity perspective was adopted.

In addition, the PI visited the Santa Fe Institute (SFI) in New Mexico, USA, which is the American centre for complexity research, to keep up-to-date with developments in other disciplines; the PI and the main researcher, together or separately, attended conferences and workshops on complexity worldwide, and all the events under the SEBPC Programme on Legacy. The latter was particularly useful in exchanging findings with all the other projects under the SEBPC Programme and in gaining understanding of how the thinking on legacy was evolving.

The project used a multi-method approach with its four collaborators dependent on the objective to be met. These objectives are summarised below.

The **primary objective** was to test the hypothesis that if information systems (IS) development co-evolves with the business process then the legacy problem will be reduced. The two case studies in the Bank and Building Society found evidence to support this hypothesis. Moreover, the research identified some of the enablers and inhibitors of *co-evolution* between the business and IS domains. One of the **outcomes** was the identification, articulation and description of an *enabling infrastructure*, i.e. the socio-technical conditions that facilitate co-evolution. The research has shown that *legacy* is not solely a technical issue but a socio-technical one and that it arises from the inter-relationship and interaction of business, organisational and technological factors, which are part of the organisational social ecosystem, embedded within a broader environmental ecosystem. It also showed that legacy is a notion that can be applied to strategy, procedures, methods of working, etc. and is part of the history and culture of an organisation. Also that legacy is not always a problem but may be an inherited asset.

The **second objective** was to study the nature of change in the business process by taking into account the generic characteristics of complex adaptive systems; and to suggest an approach for the understanding of organisations as complex evolving systems. This was achieved through the Humberside TEC study, using both a longitudinal and ethnographic approach and the BT culture study using a multidisciplinary team and intensive workshops. Further papers are planned based on continuing analysis of this material.

The **third objective** was to understand the development processes for large IT systems, which directly support evolutionary business processes. The issue was explored in the Bank and Building Society case studies. Two aspects can be highlighted. One is that continuous short-term, incremental changes to the IT systems, trying to adapt to changes in the business process, contributed significantly to the legacy problem. The second aspect is that it was extremely difficult to jettison the legacy system; in the Bank it was 'cleaned up', separated into modules which were then incorporated into a system using new technology. The individual modules were then gradually replaced. In the BS the necessary functionality of the legacy system was isolated and linked to the new systems, which seemed to proliferate. In both cases working closely with the business domain facilitated the technical process.

The **fourth objective** was to identify and develop models, tools and approaches, from the sciences of complexity, which will support the evolution and development of information systems, and enable them to co-evolve with the business process, thus reducing the problem

of legacy systems. The research has produced a *conceptual framework* to facilitate the co-evolution of the two domains, and has identified some of the *practical enabling and inhibiting conditions*, present in the two case studies, that created an enabling environment. It has also examined the NK-model as a tool to study co-evolution between IS development and business changes. This model was, however, found inadequate in a social systems context, and the project investigated agent-based modelling.

The **fifth objective** was to create a Lexicon of complexity terms with specific reference to organisational complexity. This is available in summary form on-line as well as part of several papers by Mitleton-Kelly and by Mitleton-Kelly & Papaefthimiou. <http://is.lse.ac.uk/complexity>

Finally the project contributed to the SEBPC Programme as a whole by introducing a different theoretical perspective and the concept of co-evolution, and by focussing on the inter-relationship between the two main domains. Presentations were made at SEBPC workshops and three chapters were contributed to the two books published under the Programme and edited by Prof. Henderson.

FURTHER RESEARCH & DISSEMINATION ACTIVITIES

Mitleton-Kelly and Papaefthimiou made 18 major conference/seminar presentations, published 4 chapters in 3 books (more are forthcoming); and the PI gave a Radio 4 interview. The period covered by the publications and presentations includes 1997, as the preliminary one-year project and the main three-year project, were both funded under the SEBPC Programme.

Two reports were presented to the Bank in April and October 1999; and one report was given to BS in February 2000. The Humberside TEC multi-perspective narrative was distributed in December 2001 to all the business partners, business and academic Advisors and Research team in the new EPSRC-funded project ICoSS and will be made available at all seminars, workshops, etc. Further work is being done on the TEC report and the multi-perspective method will be used in ICoSS.

The LSE Complexity Group runs two series of Seminars on Complexity and on Organisational Learning with invited speakers; a series of Workshops led by the Complexity Group, and a series of Study Group meetings (SGs). The Seminars and Workshops are open to the business and academic communities while the SGs are primarily for academics. The EPSRC awards help with these series, by contributing to the funding of a part-time administrator who administers the projects and the Seminars, Workshops and SGs. The projects provide material for the Study Group meetings, while the seminars, which are led by invited speakers from academia and the business community, working with complexity, enrich and extend our understanding of this new discipline. In addition, the Seminars, Workshops and SGs have proved invaluable for dissemination and have introduced many academics and business people to complexity and have helped *build a community of interest* in the UK.

The LSE Complexity Group is seen as a leading-edge research group on complexity in social systems, world-wide and was invited by the World Bank to lead a series of seminars at its head-quarters in Washington DC. One of the Group's researchers, Katerina Nicolopoulou, was awarded a 5-month internship in Washington DC, by the World Bank. She produced a

widely acclaimed report for the Bank's benefit and was able to use the data to complete her PhD. Dr Nicolopoulou is now working for Insead in Paris. She is also the co-author of one paper to appear in the volume edited by the PI, to be published by Elsevier in Summer 2002.

The PI was invited to become an Advisory Board Member on Complexity to Citibank New York in 1997-8. She was also invited to become an advisor and member of the USA Complexity network working with the Voluntary Hospitals Association. Because of her wide network in the business community and her work in complexity (both made possible by the 3 EPSRC awards) she was also invited to be the Coordinator for Links with Industry and Government in the new Network of Excellence funded by the European Commission. The Network includes most academics working on complexity throughout Europe and is due to start in April 2002.

The methodology pioneered in the EPSRC-funded Legacy and Aerospace Projects will be used in the new ICoSS project. This is a 3-year collaborative, action-research project with Shell Internet Works, BT's Brightstar (both are business incubators), Norwich Union, Rolls-Royce Marine (NU & RR have both undergone mergers) and the Mondragon Cooperative Corporation in the Basque Country (a non-traditional organisational form). The project will seek to identify the conditions, which will facilitate the emergence of a new organisational form after a merger or acquisition, the spinning-off of a new business, or restructuring, using complexity as the theoretical framework. The agent-based modelling investigated in the Legacy project will be used in the ICoSS project. Co-evolutionary models produced by Per Bak and Ricard Sole also need to be investigated further.

RESEARCH IMPACT & BENEFITS TO SOCIETY

The expected benefits outlined at the time of the proposal, have all been met and the section above has covered many aspects of the impact the research has had and its benefits. The business community and other researchers working in the field of complexity have benefited through the Seminar series, the Workshops and the Study Group meetings. In addition the presentations made at the SEBPC workshops introduced that community to a new discipline and to the concept of co-evolution, and contributed to an understanding of legacy systems. The project has also provided a practical application to test the theory of complex social systems being developed by the LSE Complexity Group. The collaborators and other organisations will benefit from the concept of an 'enabling infrastructure' based on socio-technical conditions that facilitate the co-evolution of related business domains. That is, the application of the concept extends beyond the relationship between IS development and the business process. Related entities do co-adapt and co-evolve, but this process can be hindered or slowed down unintentionally. The importance of the research was in articulating the concept and in identifying some conditions that may inhibit and facilitate co-evolution. Extending this notion is also the idea of accelerating the *rate of co-evolution*.

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