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# Concepts from Coevolution in Information Systems

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## ABSTRACT

This paper provides an overview of definitions and concepts from coevolution that may be useful in the domain of information systems (IS). Both the management literature and the information systems literature are reviewed to highlight insights that have been drawn from coevolution. Aspects of coevolution that have been considered important in the literature include the dynamic, emergent nature and the multi-levelness of coevolutionary processes. The nature of the coevolutionary relationship has not received as much attention. This paper presents a classification scheme drawn from Thompson (2005) that can be used to explore the nature of coevolutionary interactions in more depth. It is suggested that future IS research applying a coevolutionary framework can be enhanced with a deeper consideration of the nature of the interactions and with the incorporation of theories from the social sciences.

## Keywords

Coevolution, information systems.

## INTRODUCTION

The discipline of information systems (IS) sits at the intersection between the areas of business, technology and the social sciences and the IS community has always drawn on theories, frameworks and methodologies from disciplines related to these areas. Although biology and ecology have not played a large role as reference disciplines for IS, there has been some interest in applying coevolutionary frameworks to management related fields, including information systems (Benbya and McKelvey, 2006; Vidgen and Wang, 2006; Peppard and Breu, 2003). Gregor (2006) advocates the development and adoption of multiple theory types within the IS domain and highlights the importance of critically evaluating the underlying assumptions that determine the nature of the theories and how they are used. This paper will explore the current and potential contributions from the study of coevolution to various areas of information systems. Research in this area is at an early stage of development, so it is an ideal time to evaluate which areas of IS might benefit from the use of a coevolutionary framework and how a coevolutionary lens can best be applied.

Coevolution, like information systems, sits at the intersection of different fields – biology and ecology – and this is one of the characteristics that makes coevolution a potentially powerful conceptual tool in the domain of IS. In coevolutionary theories, relationships are modeled as ongoing processes with reciprocal influences and these underlying assumptions have the potential to enrich theories in the information systems domain. However, it is important to proceed with caution when applying theories from one discipline to a fundamentally different discipline. Some aspects of coevolutionary theories may be analogous to the information systems domain, but other aspects are likely to be irrelevant. Benefits may be realized in terms of novel insights and innovative explanations, but it is important to critically evaluate the extent to which the concepts apply in the foreign domain.

This paper starts with a summary of definitions and concepts from coevolution that may be useful in the domain of IS. The management literature is then reviewed to highlight insights that have been drawn from coevolution in various management related areas. Many areas of information systems are closely related to management, so it would be reasonable to expect that applications of coevolution in IS could draw on the experiences of management research applying coevolutionary concepts. Coevolutionary approaches in the information systems literature are then reviewed. Finally, suggestions are made for future coevolutionary research in information systems with consideration of concepts that can be usefully applied in the new domain and limitations that must be kept in mind.

## COEVOLUTION

According to Janzen (1980) coevolution involves an:

“evolutionary change in a trait of the individuals of one population in response to a trait of the individuals of a second population, followed by an evolutionary response by the second population to the change in the first.”

Futuyma and Slatkin (1983) describe evolution as focussing on one particular species with all influences considered to be part of the environment, whereas coevolution, is a more specific and dynamic process which focuses on the reciprocal interaction between two evolving species. A distinctive feature of coevolution is that the selective factor which stimulates evolution in one species is itself affected by that evolution. Evolutionary perspectives consider the environment to be static and do not specifically address reciprocal influences between species. To satisfy the strictest definition of coevolution, the following three characteristics must be exhibited (Janzen, 1980):

- Specificity – one trait evolves to a specific trait in another species
- Reciprocity – traits in both species must evolve because of each other
- Simultaneity – traits in both species must evolve at the same time

Diffuse coevolution relaxes the specificity requirement and allows that a trait in one species may evolve due to a trait (or suite of traits) in several other species. An example of diffuse coevolution is the development of chemical and physical defenses in plants against a number of different types of insects with a corresponding development of the insects' detoxifying abilities against a wide range of plant chemicals. If all three of the above characteristics are absent – diffuse coevolution with no simultaneity or reciprocity – it becomes equivalent to evolution. In the IS domain, a coevolutionary lens could be applied to the development of information technology (IT) infrastructure in relation to the IT needs of diverse business units. Diffuse coevolution would seem to best describe this type of relationship, while more specific coevolutionary processes might govern the development of applications or services that are exclusive to one particular business unit.

Coevolution in the biological world can take place at different levels including individuals, populations of individuals and entire species. In the corporate world, the analogous levels would be individuals or individuals and technology, business units, organisations and networks of organisations. A large variety of biological species participates in coevolutionary relationships including plants and herbivores, plants and insects, hosts and parasites, predators and prey. Since the main goal of this paper is to evaluate the effectiveness of using a coevolutionary framework in the domain of IS, the type of species involved is not directly relevant. The 'species' in IS is inherently defined by the level that is being considered, as outlined above, ranging from individuals or technology through to networks of organisations.

Coevolutionary interactions can be seen to exist on two continuums. First, there is the degree of harm or benefit to each of the interacting species. Interactions may be either antagonistic, where one species negatively affects the other's fitness, commensalist, where the effects on both species' fitness levels are neutral, or mutualistic and beneficial to both species. The nature of the coevolutionary relationship is also defined by the proximity of the relationship between the species along a continuum ranging from symbiotic relationships to free ranging entities. In the domain of IS, the nature of the interaction / relationship is likely to be relevant and will be examined in further detail here. The proximity of the relationship is not directly applicable to IS beyond the obvious fact that for coevolution to occur in any domain, there must be some contact between 'species'.

The following table (adapted from Thompson, 2005) organises the nature of coevolutionary relationships into seven different classes and identifies the primary forms of selection for each class. The first four classes represent antagonistic dynamics between the coevolving entities while the next two represent mutualistic dynamics. The final class differs from the rest in that the interactions between the entities decrease over time as selection pressures are exerted. The second column highlights factors that will influence the coevolutionary process. Interestingly, it is primarily the mutualistic classes that have stabilizing dynamics. For applications in IS, if stability is a desired outcome, then mutualistic coevolutionary relationships should be facilitated. Thompson's findings (2005, p261) suggest that some antagonistic relationships evolve towards mutualism and insights into the selection pressures that influence this evolution may provide IS researchers and practitioners with clues about how to influence these dynamics.

<b>Coevolutionary dynamics</b>	<b>Primary forms of selection</b>
Coevolving polymorphisms	Negative frequency dependent and short-term directional
Coevolutionary alternation	Multispecific fluctuating selection
Coevolutionary escalation	Directional
Attenuated antagonism	Directional, stabilizing, and density dependent
Coevolving complementarity	Positive frequency dependent, stabilizing, and directional
Coevolutionary convergence	Positive frequency dependent, stabilizing, and directional
Coevolutionary displacement	Directional

**Table 1. Classification of Coevolutionary Dynamics (adapted from Thompson, 2005, p89)**

A common example of the first class of coevolution, coevolving polymorphisms, occurs when there is a species being attacked and the individuals with rare characteristics are more likely to survive the selection process because the attackers have evolved to favour the most common form of victim. Over time the rare characteristic in the species being attacked will become more common. According to (Thompson, 2005), studies on the coevolution of Australian wild flax and flax rust represent one of the most significant examples of coevolving polymorphisms. This type of coevolution might be used as an analogy for the relationship between operating systems and viruses in IS. Viruses are more likely to be developed for the most common form of operating system (Windows on desktop PCs) and because of this, less common operating systems, such as Linux, may gain a stronger position in the market.

The dynamics of coevolving alternation differ from the previous class because of the ability of the attackers to actively choose their victims. Examples of this class occur more often with free ranging species eg. predators and their prey. Davies and Brooke (1989) propose that this dynamic governs the coevolution between cuckoos and host species in England. Coevolution occurs as attackers change their preferences and victims' levels of defence change. Attackers choose victims with the lowest levels of defence, so selection favours victims with the best defences and attackers that prefer the least defended victims. The victims that are not being attacked will not evolve stronger defences because there is a fitness cost involved in developing defences. So, over time, the preferred victim with the low level of defence will become less abundant and will also evolve stronger defences. Attackers with a preference for the previously ignored victims will then be favoured by selection resulting in an alternation of preference / defence ratings. Continuing with the security analogy from the previous paragraph, hackers might originally choose to develop viruses for the most vulnerable environments. Efforts to develop and deploy anti-virus software will strengthen these environments and hackers may then focus their efforts on other less well protected environments.

Coevolutionary escalation is an extension of coevolutionary alternation with the levels of defense and counterdefense in both species continuously increasing. This type of coevolution is sometimes referred to as a coevolutionary arms race or the 'Red Queen Principle'. The name comes from the statement by the Red Queen in Lewis Carroll's "Through the Looking Glass" that "in this place it takes all the running you can do to keep in the same place". There is an abundance of biological examples of this type of coevolution. For instance, the spines and shells of Murex snails have continuously evolved, becoming thicker and harder while predators such as crabs and fish have developed ever more powerful claws and jaws. An important insight from Thompson's (2005) findings is that coevolutionary escalation will not continue forever as it is limited by tradeoffs imposed by competing selection pressures. In the corporate world, as businesses fight for market share, investments in IT are often viewed as necessary for survival but of limited value in terms of sustainable competitive advantage because of the ongoing investments of rival companies in similar systems and capabilities. So, organisations are participating in coevolutionary escalation as they continuously invest in IT capabilities only to remain on even terms with their competitors.

Attenuated antagonism sits on the edge between antagonistic and mutualistic relationships between species. A classic illustration of this type of relationship is the Myxoma virus introduced in Australia to control the population of rabbits. The virus is carried and spread by mosquitoes. The most virulent strains of the virus did not persist because they resulted in the death of infected victims preventing any further spread of the virus. Over time, the rabbits were able to develop defences against the less virulent strains of the virus. A parallel example in the domain of information systems could be when a website goes live, attracts an unexpectedly large number of visitors and subsequently crashes because of an inability to handle the load. Users who develop a negative impression of the offering may never return to try again. A less ambitious launch that originally only attracts a small number of users may evolve to attract and retain large numbers of users over time.

Coevolving complementarity and coevolutionary convergence both involve the concurrent evolution of complementary traits in two different species such that the fitness of each species is increased. Coevolutionary convergence is an extension of complementarity where traits in several species evolve to complement the reciprocal trait(s) in the coevolving species. The ant/acacia relationship is an often cited example of this type of mutualistic coevolution where the acacia has evolved to provide suitable food and shelter for the ants, while the ants protect the acacia from herbivores and fungal diseases. These mutualistic relationships would seem to be the ultimate goal for business and IT relationships within a corporation. Any insights from the biological world that can offer improvements in this area would be welcomed by researchers and practitioners focussing on strategic alignment between business and IT. Advances in hardware and software development can also be viewed as a coevolving complementarity process, with advances in each stimulating and supporting further advances in the other.

The final category – coevolutionary displacement – eventually results in a separation of the two species so that the coevolutionary relationship comes to an end. The case of the Anolis lizards in the Lesser Antilles represents a biological example of this type of coevolution. Due to competition for resources (food and habitat), different species of the lizards evolved to inhabit completely distinct geographical areas. An analogous example in the corporate world would be companies that originally compete in various areas and eventually evolve to focus on distinct market niches.

This section has explored various characteristics of coevolution with a focus on the different types of coevolutionary relationships. Thompson's (2005) classification of coevolutionary relationships was outlined and a biological example was used to illustrate each type of interaction. A hypothetical application to the IS domain was suggested for each class of relationship. In the next two sections, the application of coevolutionary concepts in the management and IS literature will be reviewed in the context of the previous discussion. The evaluation will consider whether the characteristics of reciprocity, simultaneity and specificity have been assumed, the level at which the coevolutionary lens has been applied, the type of 'species' to which it has been applied and whether the nature of the coevolutionary relationship has been explored in any depth.

## COEVOLUTION IN THE MANAGEMENT LITERATURE

Lewin and Volberda (1999) argue that using coevolution as a theoretical framework has the potential to lead to "new insights, new theories, new empirical methods, and new understanding". They contend that one of the main benefits of using a coevolutionary framework in the domain of management is the inherent integration of an external (selection oriented) focus with an internal (adaptation oriented) focus. Coevolution, because it sits at the intersection of biology and ecology, looks simultaneously at internal and external influences to describe and explain the development of various phenomena. Historically, the management literature has been split with the strategic management literature focusing on internal processes such as firm adaptations and managerial intentionality while organization theory has focused on external processes, such as industry selection pressures, acting on variation and retention processes. Hoskisson, Hitt, Wan and Yiu (1999) provide a historical summary of this dichotomy in the management literature.

Lewin and Volberda (1999) apply a coevolutionary lens to the relationship between firms and their environment with the interaction between industry selection pressures and firm level adaptation resulting in new organizational forms. The 'species' considered are the firm and its environment which represents a model of diffuse coevolution. The focus is mainly on the development of new organizational forms that result from environmental influences, so reciprocity is not a critical element in their analysis. Microcoevolution is characterized by Lewin and Volberda (1999) as processes of change involving intraorganizational elements and macrocoevolution is defined as coevolution that occurs between a firm and one or more components of the external environment. An important aspect of their research is the integration of these two levels which is facilitated by the coevolutionary model. The dynamic and emergent nature of coevolution is also a key factor in understanding the underlying processes that result in new organizational forms. They distinguish between zero-sum competitive, pluralistic competitive and cooperative coevolutionary systems and identify research characterized by these

different types of relationships. However, their research on the emergence of new organisational forms does not seem to consider the type of relationship as an important dimension.

Lewin and Long (1999) and Dijksterhuis and Vanden Bosch (1999) also use a coevolutionary lens to analyse the emergence of new organizational forms, with an emphasis on the dynamic and multi-level nature of coevolution. In line with the research of Lewin and Volberda (1999) these analyses fall under the category of diffuse coevolution and the reciprocity of effects is not emphasized. The effects of the environment on the emergence of organizational forms is the main focus and the nature of the relationship (antagonistic vs mutualistic) is not highlighted.

McKelvey (1999) draws on concepts from coevolution and complexity theory (Kauffman, 1995) to explore strategic moves made by firms and how they relate to competitive advantage. Once again, the dynamic, ongoing nature and multi-level aspects of coevolution are considered key to the analysis. McKelvey's (1999) model can be characterized as diffuse coevolution – the changes made by a firm in response to changes in its environment which includes competitors, technology, markets, and government policy. The reciprocal effects on the environment are not the main focus of the analysis. The type of relationship is highlighted to some extent. For example, reference is made to competitive coevolutionary pockets of competing firms.

Eisenhardt and Galunic (2000) advocate the benefits of using a coevolutionary framework to manage collaboration between business units within a firm. Their research espouses a dynamic, emergent approach to collaboration in order to maximise benefits from cross-business synergies. They also advocate rewarding individual performance (manipulating selection pressures), identifying high leverage links (nonlinear effects) and blurring the distinction between collaboration and competition (supporting antagonistic and mutualistic relationships). The coevolving 'species' in this research are the business units within the firm. The nature of the coevolutionary relationships is not explored in depth. They suggest that the role of corporate level managers is to set the context for coevolution which involves encouraging business unit managers to communicate and focus on the potential synergies between business units.

Koza and Lewin (1998, 1999) use a coevolutionary framework to examine how a firm's strategic alliances change over time. It is the dynamic aspect of coevolution which is most relevant in their analysis. The multi-level characteristics involving the firm's external environment and managerial intentionality are also a key factor. Their argument is that a firm's strategic alliances "co-evolve with the firm's strategy, the institutional, organizational and competitive environment, and with management intent for the alliance". So, once again, the focus is primarily diffuse coevolution and reciprocal influences are not a key factor in the analysis. Their findings suggest that a firm's portfolio of strategic alliances is influenced by the strategic intent of the alliances with a focus on either exploration or exploitation opportunities. The nature of the relationships is not explored from a coevolutionary perspective.

In relation to the definition of coevolution in the previous section, the management literature seems to focus mainly on diffuse coevolution where an aspect of a firm is studied in relation to its environment. Consideration of multiple levels and the dynamic, emergent nature of the coevolutionary process are emphasized in all of the literature explored here. The nature of the relationship is considered important to some extent. Other researchers have also classified different types of relationships in their research including Baum (1999), who using Heylighen and Campbell's (1995) competitive configurations illustrates zero-sum, purely competitive, partly competitive, synergistic and independent interactions and Hamel (1991) who looks at international alliances that start out to be synergetic and end up being supercompetitive.

## **COEVOLUTION IN INFORMATION SYSTEMS**

Mittleton-Kelly and Papaefthimiou (2000) look at the relationship between the business and IS domains in a major international financial institution and argue that coevolutionary processes facilitated solutions to the legacy problem. More specifically, they argue that "the degree, intensity and density of interaction between the business and IS domains affect the rate of coevolution". They look at the degree of fitness which arises because of new organisational forms which are better able to deal with the problem of legacy. Different levels are considered important including the interaction between individuals, the interaction between individuals and artefacts (technology), and the interaction between the business and IS domains up to and including the relationship between the organisation and its environment. Although the different levels are highlighted, coevolution is mainly considered between the business and IS domains. The analysis does consider reciprocal effects between both domains. Emergence is an important element of the process with the ability to experiment with different solutions and the ability to self-organise identified as key factors in the success of the project. Ongoing change is also highlighted as a key factor in the ability to iteratively determine and refine requirements and feedback is an important

moderator of the coevolutionary process. The nature of the relationship between the business and IS domains is not characterised in any detail.

Peppard and Breu (2003) and Benbya and McKelvey (2006) both look at strategic alignment as a coevolutionary process and identify the need for a dynamic, reciprocal approach to strategy development between IS and business. Benbya and McKelvey (2006) consider the various levels involved in strategic alignment – individual, operational and strategic. Peppard and Breu (2003) present a model that represents key factors involved in the coevolutionary process of strategic alignment. In both cases, the research draws heavily on complexity theory which will not be considered here as the purpose of this paper is to focus on concepts drawn from coevolution. The research also builds on the earlier work of McKelvey (1999) as discussed in the previous section.

Coevolutionary frameworks have been used to study the process of virus and antivirus evolution. In this domain, the relationship between the coevolving entities is almost certainly antagonistic and in most cases, coevolutionary escalation best represents the dynamics of the relationship. Reciprocal effects are inherently considered when applying a coevolutionary lens to this area. Nachenberg (1997) describes the development of polymorphic viruses and antivirus responses using generic decryption. The application of coevolutionary theory in this area of IS would seem to be an obvious match – even the vocabulary draws on concepts from biology, suggesting that insights from coevolution could greatly enrich theory and practice in this area of IS.

Vidgen & Wang (2006) apply a coevolutionary framework in the area of business process management (BPM) to evaluate whether it has the potential to obliterate the IT / business divide. Their analysis considers four main ‘species’ that may exhibit coevolutionary relationships: business processes, software components, IT developers and business users. They consider the nature of the relationships between these various components to some extent and provide some suggestions for facilitating coevolutionary development. For example, to enable coevolution between IT developers and business users they suggest “multi-disciplinary teams, success criteria based on delivering business benefits and close physical proximity”. They highlight the importance of including a social perspective when applying a coevolutionary framework to any domain involving people. Support for this suggestion is drawn from Capra (2002) who advocates the inclusion of a social perspective in order to avoid the limitations associated with the machine metaphor.

## CONCLUSION

This paper has reviewed concepts from coevolution that may be useful in the domain of IS. A definition of coevolution was outlined, identifying characteristics that differentiate coevolution from evolution – reciprocity, specificity and simultaneity. Various aspects of coevolution were discussed including levels of application, species involved, and types of coevolutionary relationships. Thompson’s (2005) classification was used to describe the different types of coevolutionary relationships and to identify the primary forms of selection influencing each type. This background was then used to explore the management and IS literature for applications of coevolutionary concepts.

In the management literature, the concurrent consideration of multiple levels and the dynamic, emergent nature of coevolutionary processes were used to gain insights into various relationships. The relationships considered included business units within a firm, strategic alliances between firms and interactions between a firm and its environment. In the IS literature, the dynamic, emergent nature of the coevolutionary model was also considered a key element of the framework. Multiple levels were often explored, as in the management literature, and the relationships considered were extended to include relationships to artifacts or technology. Specific reciprocal effects were frequently considered in the IS literature.

Due to space limitations, the literature considered here represents only a sample from the management and IS disciplines. A more comprehensive review which also integrates literature drawing on concepts from evolution and complexity would help to inform future research. However, the preliminary exploration here has highlighted several potential directions for future coevolutionary research in IS. A stronger focus on reciprocal, specific effects and a deeper consideration of the type of coevolutionary relationship could provide further insights into various areas of information systems. This review has made an effort to demonstrate that when drawing on coevolutionary concepts it is important to evaluate which concepts are applicable in the new domain and to continuously draw on the foundation of research from the original discipline.

A further recommendation for future research is to integrate theories from the social sciences with research that uses a coevolutionary framework. Vidgen and Wang (2006) suggest that Habermas’ critical theory and Giddens’ structuration theory represent good candidates for application in this domain. In biology, the primary ‘motivation’ for any development is survival. Human actors have various other priorities and an acknowledgement of these will lead to a deeper, richer understanding of any human activity system. Beyond improved understanding, coevolutionary frameworks have the potential

to provide insights into the manipulation of ‘selection pressures’ for achieving improvements in human activity systems. Theories from the social sciences, such as Ulrich’s (1983) purposeful systems theory, can be used to enhance research in this area with the incorporation of human intentionality.

In the spirit of coevolution, it would be interesting to explore to what extent the information systems discipline has affected and has the potential to affect the study of coevolution. Obviously, IT tools are used extensively for data collection, storage and manipulation and simulations play a role in theory development and validation. There may be further unexplored areas where theories and techniques from information systems can provide new insights for researchers studying the phenomena of coevolution.

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