Journal of the Association for Information Systems

Volume 15 | Issue 9 | Article 2

9-21-2014

A Coevolutionary View of Information Services Development: Lessons from the U.S. National Oceanic and Atmospheric Administration

Ramiro Montealegre
University of Colorado at Boulder, ramiro.montealegre@colorado.edu

Dirk Hovorka
University of Sydney, dirk.hovorka@sydney.edu.au

Matt Germonprez
University of Nebraska at Omaha, mgermonprez@unomaha.edu

Recommended Citation

Montealegre, Ramiro; Hovorka, Dirk; and Germonprez, Matt (2014) "A Coevolutionary View of Information Services Development: Lessons from the U.S. National Oceanic and Atmospheric Administration," *Journal of the Association for Information Systems*, 15(9), .
DOI: 10.17705/1jais.00372
Available at: https://aisel.aisnet.org/jais/vol15/iss9/2

Journal of the Association for Information Systems
JAIS

Research Article

A Coevolutionary View of Information Services Development: Lessons from the U.S. National Oceanic and Atmospheric Administration

Ramiro Montealegre
University of Colorado at Boulder
Ramiro.Montealegre@colorado.edu

Dirk Hovorka
University of Sydney
dirk.hovorka@sydney.edu.au

Matt Germonprez
University of Nebraska at Omaha
mgermonprez@unomaha.edu

Abstract

This study investigates the process of information services development based on a case study of the experience of the U.S. National Oceanic and Atmospheric Administration (NOAA). In this study, we develop theoretical constructs that can inform researchers and practitioners on (1) what the critical domains and interactions associated with the emerging process of information service development at these organizations were, and (2) how information services at NOAA evolved over time? Adopting a coevolutionary view, we identified distinct yet interdependent domains that affected, and were affected by, the information services development process; these were: (1) services choreography, through which service interactions and collaborations are managed; (2) services orchestration, through which service processes are selected and interact; and (3) services instrumentation, by which services are developed and architected. Using the coevolutionary view, we uncovered three adaptive principles that explain the interplay among domains and interactions over time: adaptive tensions, requisite variety, and modular design. We discuss our findings' implications for research and practice and offer propositions for future research.

Keywords: *Information Services, Development of Information Systems, Coevolution Theory, Case Study Research.*

* Michael Barrett was the accepting senior editor. This article was submitted on 2nd February 2012 and went through four revisions.

Volume 15, Issue 9, pp. 577-613, September 2014

A Coevolutionary View of Information Services Development: Lessons from the U.S. National Oceanic and Atmospheric Administration

1. Introduction

An emerging vision among researchers, consultants, and business analysts is that corporate environments connect people, places, and things through information services enabled by a heterogeneous set of networked technologies. In this vision, scalable, cost-effective information technology (IT) capabilities need to be provisioned as information services, delivered as information services, metered and managed as information services, and purchased as information services. This vision, which has been referred to as “service-centric computing”, “information technology services”, “information on demand”, and “computing grid”, shifts the focus from infrastructure (e.g., hardware, software, and the complexity of day-to-day operations) to information services and their inherent organizational, managerial, and technical considerations. Despite the recognition that developing services is not a simple, linear process, many conceptions of information services are premised on a rationally planned and controlled development process through which alignment is automatically obtained (Hanseth & Lyytinen, 2010; Hirsheim, Welke, & Schwarz, 2010). Little evidence of the emergent, dynamic processes among social, technical, and organizational elements is available for practitioners and researchers to understand the reality of information services development and the critical domains and interactions that need to be considered.

The current literature does not fully articulate either theory critique or theory development regarding a coherent view of information services development that accounts for their open-ended and context-specific properties. Furthermore, although there are numerous studies on the technologies underlying information services (such as service oriented architecture, resource oriented architecture, and Web 2.0 technologies), few studies empirically sufficiently explain organizational information services development over time. Theory frameworks have been used to consider the economics of organization information services (Gurbaxani, Melville, & Kraemer, 2000; Konana, Gupta, & Whinston, 2000) and through a theory-informed business process engineering framework (Xiao & Greer, 2007). Only recently has the information systems (IS) community recognized the need to critique and develop new theory to inform this area of concern (Alter, 2009; Lu & Ramamurthy, 2011; Rai & Sambamurthy, 2006). The information services stream of research has placed increasing social and technical complexity and socio-technical adaptation and evolution at the center of research scrutiny (Hanseth & Lyytinen, 2010). At the same time, however, organizations lack understanding of the tensions and adaptations that information services development projects will encounter, and thus lack guidance on how such projects progress.

In this paper, we view information services development as a process that spans levels of analysis and involves continual adaptation and change over time. This process involves a dynamic interplay between actors in distinct socio-technical domains who rely on information to support decision making and coordinate collective action in a context of evolving organizational goals and practices. Actors are highly diverse because they include managers who make decisions and choices on behalf of specific functional departments in an organization, developers who participate in acquiring, designing, developing, and deploying technology at the programmatic level, and users who envision desired goals and create meaning and value by continuously creating and re-creating specific information services.

We argue that, to better understand how information services are developed in organizations, we need to address two dimensions: what changes in the dynamic process of information service development, and the process of how it changes. Coevolution theory offers a theoretical framework to understand these dimensions. As prior research using coevolution theory in organizations has shown (see, for example, Benbya & McKelvey, 2006; Kim & Kaplan, 2005; Vessey & Ward, 2013), this perspective is useful in focusing on emerging forms that better fit contextual shifts through a process of variation-selection-retention. Thus, coevolution theory highlights the differential effects of the structure and process of change in organizations. In addition, it informs “research in organization studies, which spans levels of analyses and involves adaptation over time” (Lewin & Volberda, 1999, p. 520). As such, in this paper, we develop theoretical constructs that can inform researchers and practitioners on the dynamic process of information services development. We accomplish this by adopting a coevolutionary view in investigating the U.S. National Oceanic and Atmospheric Administration's (NOAA) efforts to develop information services. We focused on two research questions:

1) What were the critical domains and interactions associated with the emerging process of information service development?

2) How did information services at NOAA evolve over time?

In this paper, we make three main contributions. First, we apply coevolution theory from a multi-level perspective to understand the process of developing organization information services. Prior research has noted that technology development is not necessarily predicable from the start and that anticipated, emergent, and opportunity-based change processes "represent a significant (and therefore challenging) departure from the standard practice in effect in many organizations" (Orlikowski & Hofman, 1997, p. 21). This study presents one of the first in-depth empirical studies to use coevolution theory and specific mechanisms of adaptation over time in IS research. Second, by analyzing the rich data of NOAA's experiences in information services development through the lens of coevolution theory, we propose a coevolutionary view of information services development and formulate seven research propositions that have the potential to inform and aid future research on this topic. Third, we identify critical domains and interactions associated with information services that can be used in managing the emerging process of its development in organizations.

2. Theoretical Background

2.1. Information Services

In a broad sense, an information service is a service that provides data, information, and/or knowledge. The vision of information services, as mentioned above, is the realization of user-enabled, real-time production of ad hoc information systems in organizations. This vision embraces processes by which developers expose information and processes that allow users, of their own accord, to select and configure information services that fit "the idea of the arising of something from out of itself, or emergent properties, and behavior" (Gregor & Jones, 2007, p. 326). Information services make multiple, heterogeneous information sources discoverable and accessible by coordinating, encapsulating, and decoupling information and functionality from specific technology. In this vision, the user, rather than the developer, makes decisions about the relationships among information services, types of pertinent data, and what objects functionally go together as representations of the real world (Hovorka, 2005).

The technologies underlying information services, such as service oriented architecture (SOA), place considerable power and responsibility in the hands of users for the agile creation of customized functions and for participation in the services alignment process. There is a strong disconnect, however, between the espoused, technical view of information services and the understanding of the organizational relevance they provide (Hirschheim et al., 2010). Scholars are increasingly recognizing that the technical specifications of information services are only one element of a broader organizational architecture that "transmute organizational structures and behavioral practices" of enterprise-wide directives and structures and information services management (Bieberstein, Bose, Walker, & Lynch, 2001, p. 691). Information services require services discovery, loose coupling based on standardized interfaces, usability achieved by hiding technical implementation details, and the orchestration of related services in response to the demands of organizational processes (Rai & Sambamurthy, 2006).

Information services development enables the "agile creation of new services by integrating existing data from a variety of sources, not only structured and internal data, but also unstructured or semi-structured external content" (Hirschheim et al., 2010, p. 37). Their development encompasses "the capabilities, structures, and processes with which digitized services are conceived and architected, how these services are offered and orchestrated, and how interactions for innovation and production of services are managed" (Rai & Sambamurthy, 2006, p. 329). What differentiates information services is that their consumption is an application of a service in combination with other services to develop larger, integrated systems from multiple services (Bieberstein, Bose, Fiammante, & Shah, 2006). As multiple services are integrated into newly designed systems, they become the purview of the service consumers and not the original service developers. Information services are then realized as more than just their initial technical design but also an organizational enactment of when and how to apply them.

Given the broad range and domains of information services, it is important to define the term in a specific context. The context for our research is NOAA, a scientific agency of the United States Department of Commerce focused on the conditions of the oceans and the atmosphere. NOAA's mission is: “To understand and predict changes in climate, weather, oceans, and coasts, to share that knowledge and information with others, and to conserve and manage coastal and marine ecosystems and resources” (NOAA, 2010, p. v). To carry out this mission, NOAA archives and disseminates environmental, geophysical, solar-terrestrial, and marine data collected by a variety of ground and space-based observing systems and by partners at the national and international levels. NOAA has embarked on a process of transforming dedicated “stovepipe systems” to a comprehensive information services development that was adopted at every new data management program of the institution.

Underlying the development of services is the recognition that, as social structures and technologies evolve, a level of durability and order must be maintained or imposed due to prior path-dependent decisions. Previous research has recognized that social and organizational norms, processes, and structures may become reified, and “the historic conditions under which particular technologies emerge and develop, and the forms by which they have become institutionally and socially embedded, often coalesce in ways that can make technology a recalcitrant ally” (Kallinikos, 2004, p. 141). Indeed, this tension between what is durable (Aanstead, 2011) and those organizational and technological elements that emerge through adaptation and selection (Orlikowski & Hofman, 1997; Hanseth & Lyytinen, 2010) are critical to understanding the process by which information services are developed.

Furthermore, the development of information services is not linear and predictable, and is frequently the result of improvisation, tinkering, or secondary design (Ciborra, 1994; Germonprez, Hovorka, & Collopy, 2007; Germonprez, Hovorka, & Gal, 2011; Orlikowski & Hofman, 1997). Bergman, King, and Lyytinen (2002) argue that the failure to recognize and understand how technological, organizational, and institutional changes are inherently interwoven is behind the failure of many IT services. Schreyögg and Schmidt (2010) contend that attempting to align a specific technology across all aspects of an organization is naturally inefficient and subject to failure. Instead, organizations must engage technology with the intention of shaping it through internal processes of change and emergence. Thus, information services and their realization in an organization become best viewed as “dynamic systems with multiple agents” where the traditional boundaries between technology development efforts and management alignment efforts collapse (Schreyögg & Schmidt, 2010, p. 155).

The extant literature on information services has largely focused on the technical aspects of communication and control. Research on IS alignment (Benbya & McKelvey, 2006; Ciborra, 2002; Orlikowski, 1996; Orlikowski & Hofman, 1997), however, suggests that top-down, rational design models must be integrated with emergent processes and functional developments in the organizational context. Specifically, many of the traditional models of IS development, “in which the major steps of the change are defined in advance and the organization then strives to implement these changes as planned in a specified period of time” (Orlikowski & Hoffman 1997, p. 1), do not reflect what is actually happening during information services development.

Information services are inherently dependent ensembles in which “the outcome of technology development and use cannot be reliably predicted, as both the technical and social are mangled together in the process to produce specific, situated instantiations” (Jones, 1999, p. 299). Development occurs contemporaneously and is the purview of codependent organizational entities, not independent functional units that follow predefined sequential development. Thus, coevolution theory acts as a theoretical mechanism to surface the dynamic interplay of technical, social, and organizational elements in the development of services and provides a clearer understanding of processes than a top-down, rational, engineering-focused perspective.

2.2. Coevolution Theory

Coevolution, which in biology refers to evolutionary changes that take place in two or more interdependent species of organisms as they interact with each other, is applicable to organization-environment relationships to better understand adaption. Recognizing that the evolution of an organization cannot be understood independently from the simultaneous change of its environment, McKelvey (1999) defines coevolution in that context as "mutual causal changes between a firm and competitors, or other elements of its niche, that may have adaptive significance" (p. 299). Adaptation occurs when internal and external forces produce tensions among entities, which subsequently change to maintain fit with the overall landscape (McKelvey, 2004). Coevolution theory has received attention in the organizational and social sciences. It has been used to analyze the competitive advantage of nations (Porter, 1990), strategic management (Barnett & Hansen, 1996), strategic alliances (Koza & Lewin, 1998, 1999), new organizational forms (Lewin, Carroll, & Long, 1999; Lewin & Long, 1999; Dijksterhuis & van den Bosch, 1999), rent appropriation and capability development (Coff, 2010), institutional entrepreneurship (Pacheco, York, Dean, & Sarasvathy, 2010), and the management of collaboration among business units in a firm (Eisenhard & Galunic, 2000). In IS research, coevolution theory has been used to theorize about the alignment of business and IT (Mitleton-Kelly & Papaefthimiou, 2001; Peppard & Breu, 2003; Benbya & McKelvey, 2006; Vessey & Ward, 2013), information systems engagement (Kim & Kaplan, 2005), the co-design of organizations and information systems (Nissen & Jin, 2007), offshore outsourcing (Lahiri & Keia, 2010), and business process management (Vidgen & Wang, 2006). Following Lewin and Volberda (1999) and McKelvey (2004), we identify six properties of coevolutionary models of the strategic management and organizational adaptation research: multilevel effects, multidirectional causalities, nonlinearity, positive feedback, path- and history-dependencies, and adaptation principles (see Table 1).

Table 1. Properties of Coevolutionary Models

Property	Description	Prior research (examples)
Multilevel effects	Coevolutionary effects take place at multiple levels in firms, and between firms and their environment.	Lewin, Carroll, and Long (1999), Cohen and Steward (1994), Lewin and Volberda (1999), Pettigrew (1995), Huygens, Baden-Fuller, van den Bosch, and Volberda (2001)
Multidirectional causality	Coevolutionary effects result from multidirectional causalities in a complex system of relationships where changes in variables are caused by changes in others.	Baum (1999), Kauffman (1993), Lewin and Volberda (1999), McKelvey (1997)
Nonlinearity	Coevolutionary effects are not tractable through a simple cause-effect logic of linear relations between independent and dependent variables.	Anderson (1999), Casti (1994), Guastello (1995), Vessey and Ward (2013)
Positive feedback	Action and interactions between the environment, a firm, and its parts are recursive and result in interdependencies and circular causality.	Lewin and Volberda (1999), Pacheco, York, and Hargrave (2011)
Path and history dependencies	Adaptation in a coevolutionary process is path and history dependent. These dependencies reflect the irreversible and unexpected events undergone and shape the conditions along the approaches taken in addressing them.	Axelrod and Cohen (1999), Calori, Lubatking, Very, and Veiga. (1997), Dooley (1997), Kieser (1989), Koza and Lewin (1998)
Principles of adaptation	These principles, which build from biological and social systems adaptation, are: adaptive tensions, requisite variety, modular design, change rate, positive feedback, causal intricacy, and coordination rhythms.	McKelvey (2004), Vidgen and Wang (2009)

Taken together, these six properties stress the need to consider:

a) A multilevel view of the phenomenon—taking into account the interactions between multiple levels (Lewin & Volverda, 1999).

b) The effects that result from multidirectional causalities—when an organizational element adapts or changes to ensure fit, other elements in the organization or its context are altered, and so on, which results in continual changes (Kauffman, 1993; Vessey & Ward, 2013).

c) The effects of change that are non-linear—effects are not tractable through simple cause-effect logic of linear relations (Anderson, 1999; Guastello, 1995).

d) The interactions containing recursive relations that result in interdependencies and circular causality—each organizational element influences, and is in turn influenced by, all other elements in that organization and its environment (Lewin & Volberda, 1999).

e) The adaptive process that is path and history dependent (Calori et al., 1997; Kieser, 1989) and is used to understand the subject of the study by identifying antecedent conditions; coevolving activities, actions, and processes; and outcomes (Koza & Lewin, 1998).

f) The principles of adaption that emerge from interactions among individuals and between autonomous domains (Vidgen & Wang, 2009). Benbya and McKelvey (2006, p. 20) suggest that "having none [of these principles] is a disaster; having all greatly fosters adaptation. They are said to be 'interdependent' in the sense that they 'should not be applied in isolation if one wants to reach valid conclusions regarding coevolution adaptations".

On the basis of these six properties, we suggest that coevolution theory has the potential to inform and broaden research on information services in organizations. Inherent in information services development is the assumption that it is not straightforward and predictable (Orlikowski & Scott, 2008). Thus, the six properties of coevolution allow us to frame this phenomenon as a dynamic interplay of technologies and organizational elements that coevolve because of dynamically changing internal and external forces. Coevolution theory accounts for the historical conditions that influence the development process, such as the technical rules of a system, the social actors involved, and the previous successes and failures that shape the organizational experience of services engagement. Case studies of the development of information services over time are important source of insights about this fuzzy, indeterminate, and complex process. They more accurately reflect the authentic experience of organizational actors who seek to achieve and sustain alignment in practice. All six properties contribute to coevolutionary adaptation, but are not necessarily present at every phase of an information service's development process (Lewin & Volverda, 1999). Taking a coevolutionary perspective allows "a more emergent natural systems perspective and [one that can identify or] pick parts naturally emerging as evolutionarily significant (those more likely to change…)" (McKelvey, 1999, p. 298).

3. Research Approach

Given that little research to date has been conducted on the open-boundary, dynamic, and multilevel process of information services development, this study increases our understanding of this phenomenon and the particular elements that comprise such a process. We use coevolutionary theory for understanding and, more specifically, as an explanatory sensitizing device as Gregor (2006) describes. Importantly, we do not describe or test predictions about coevolutionary processes. Rather, we emphasize "showing others how the world may be viewed in a certain way, with the aim of bringing about an altered understanding of how things are or why they are as they are" (Gregor, 2006, p. 624). We rely "on varying views of causality and methods for argumentation" (p. 619), and apply coevolution theory as a general logic to guide this study by focusing on longitudinal time frames; multidirectional causality; linearity; positive feedback; path dependence; and multilevel, historical, and contextual information (Lewin & Volberda, 1999). This approach allows us to inductively identify specific domains and interactions associated with the development of information services at NOAA.

Furthermore, the qualitative nature of this study's research questions (Benbasat, Goldstein, & Mead, 1987) led us to use an in-depth case study research approach (Yin, 1994). Such an approach is appropriate when research needs the study of contemporary events, without the need to control variables or subject behavior (Yin, 1994).

3.1. Research Setting

For the in-depth case study, we captured rich details of a development process of information services by focusing on the dynamic interplay of coevolving interactions, relationships, and effects in a natural setting. Historically, the information systems at NOAA were developed as dedicated systems by individuals to meet the data collection archive and dissemination needs of associated user communities. Data in these systems were usually encoded in different formats and transmitted via a variety of communication systems and protocols. The application of scientific data to multidisciplinary problems was distributed across a heterogeneous assortment of standards needed to effectively identify, acquire, and correctly use all of the relevant data.

Thus, NOAA provided a case-study environment strongly focused on a mandate for the long-term creation, management, archiving, and distribution of scientific information. More importantly, NOAA provided a natural laboratory to observe how the service development process unfolded because our data collection occurred while significant changes were happening, which allowed us to record important incidents. Additionally, because we selected NOAA as our case study, we ensured that the substantive area addressed—the shift from stand-alone information systems to the development of information services—was "likely to replicate or extend the emergent theory" (Eisenhardt, 1989, p. 537). Our site selection followed Patton's (1990) advice: "The logic and power of purposeful sampling lies in information-rich cases for study in depth. Information rich cases are those from which one can learn a great deal about issues of central importance to the purpose of the research" (p. 169). At NOAA, we gained access to fine-grained, high-quality data about the development of information services over an extended period of time. The contemporary nature of this case meant that extensive documentation was accessible and key actors were available for interviewing.

3.2. Data Collection

We conducted field research (on-site observation, interviews, and documentation review) over the course of 30 months. Thus, the research involved data collected over time, and focused on the activities and decisions that were taking place as information services were being adopted. Collection of multiple types of data from different sources provided triangulation and increased the reliability of the study.

We used coevolution theory to guide our data collection. Such an approach is recommended by Patton (1990), who argues that an interview guide is useful for focusing the conversations and can also be used as a descriptive framework for analysis. As is appropriate in qualitative research, we used theoretical sampling (Glaser & Strauss, 1967). Theoretical sampling is the process of data collection whereby the researcher(s) simultaneously collects, codes, and analyzes the data in order to decide what data to collect next. In particular, we followed Glaser's (1978) advice that, in the initial stages of a study, researchers should:

> *go to the groups which they believe will maximize the possibilities of obtaining data and leads for more data on their question. They* [should] *also begin by talking with the most knowledgeable people to get a line on relevancies and leads to track down more data and where and how to locate oneself for a rich supply of data* (p. 45).

To assure that our data came from all levels of NOAA involved in the development of information services, we arranged interviews with all top and middle managers involved, the leaders of the information services development technical group, and information services users. We initially conducted seven interviews and then returned to NOAA 18 months later to interview five of the original contacts and 12 additional participants. We identified these additional participants through our analysis of the data as key sources for data collection because of their involvement in the development of information services at NOAA (see Appendix A for their job designations).

We tailored semi-structured interviews to each person: we focused on the interviewee's history, their recollection of facts and events related to the development of information services, how decisions and actions were influenced and made, and how conflicts were resolved. In the interviews, we also addressed the interviewee's role, attitude, and motivations toward information service development. We recorded and transcribed the interviews, and we noted additional observations during each interview. To minimize bias and increase the study reliability, we followed the guidance on retrospective interviewing techniques that Golden (1992) and Miller (1997) suggest, which includes using multiple knowledgeable informants to allow the information provided by any one informant to be checked against the information provided by other informants, asking informants to recall simple facts or concrete events rather than past opinions or beliefs, motivating informants by ensuring confidentiality, minimizing duration and inconvenience of data collection, and providing a rich explanation of the topic's usefulness.

At the end of each interview, we asked the subject to suggest other individuals who would be potential sources for understanding the development of information services in NOAA. Written data included both primary sources (annual reports, organizational archival analyses, organizational charts, strategic information services documents, and internal correspondence and memos) and secondary sources (relevant Internet publications). Additionally, we kept observational notes during the unfolding development of information services: included were numerous references to changes in how people viewed information services over time: concerns shifted, reactions varied, and perceptions were similar and diverse. In addition, throughout data collection, we had the advantage of access to Ted Habermann, a member of the data management integration team, a key informant who granted us several interviews. In total, this research study generated a database of approximately 35 hours of recorded interviews, 60 pages of observational notes, 132 pages of transcribed interviews (45,325 words), and over 1,953 pages of secondary documentation.

3.3. Data Analysis

Given the nature of the process data from this study, we combined several steps for sense-making, as Langley (1999) suggests, by moving back and forth between the empirical data and theoretical conceptualization. First, during the data collection, notes on the facts, specific details, and other pieces of information that several informants seemed to repeat augmented the evolving theory (van Maanen, 1983), as did ideas generated during periodic debriefing sessions among the three co-authors.

Second, we followed a narrative strategy that involved constructing a detailed story from raw data (Langley, 1999, p. 695). We used background documents, publicly available information, and transcripts of interviews and meetings to create a detailed narrative history of NOAA's information services development. Though this strategy is descriptive in nature, it provides a mechanism for condensing the large volume of data and moving toward a more in-depth case study analysis (Eisenhardt, 1989). In both the case study database and the narrative write-up, we created a chain of evidence that allows others to "follow the derivation of any evidence from initial research questions to ultimate case study conclusions" Yin (1994, p. 84). Such an approach increases the reliability of the entire study (Yin, 1994).

Third, we employed a qualitative approach designed to reveal preexisting and emerging phenomena and relationships among them. This assumes that the phenomenon under investigation was likely to follow an existing theory, but the study was not limited to examining predefined constructs. This approach was useful because it allowed us to focus on contextual and process-oriented elements and on the actions of key players associated with the development of information services at NOAA while taking advantage of what we knew about coevolution theory. The approach is consistent with Eisenhardt's (1989) theory-building process, arguments made by Mandill et al. (2000), and Kirsch's (2004) hybrid qualitative method. We followed the open coding and axial coding techniques that Strauss and Corbin (1998) propose. Open coding is concerned with both labeling the phenomena and concepts inherent in the data, and grouping these concepts into categories. Axial coding is concerned with identifying the relationships between categories and validating these relationships in the data. Following these guidelines, we categorized the data into concepts that we derived from individual and collective actions, and from the interaction between business actors and technology that appeared to have influenced the information services development at NOAA. We compared and contrasted the resulting data categories with the array of concepts discussed in the coevolution theory literature. We cross-checked our interview transcripts to verify that concepts were supported by at least two sources of evidence. As we coded data into categories, various theoretical questions, hypotheses, and code summaries arose. We captured these in analytic memos, which were subsequently used to help integrate our understanding of the phenomena and to refine further data collection. A key task in this analytical step was the creation of an event listing, a technique that can provide insight into "what led to what, and when" (Miles & Huberman, 1994, p. 110) (see, for example, Tables 3-5). Then we created critical incident charts (Miles & Huberman, 1994) depicting the sequence in which capabilities were developed (as shown in Figure 2). The concepts derived from individual and collective actions, and from the interaction between business actors and technology, represent our interpretation based on evidence gathered from interviewees. By moving from comparing incidents in a category to comparing incidents with the emerging properties of category during axial coding, we organized, clustered, and mapped the theoretical components into meta-concepts (categories and codes) as Table 2 and Figure 1 show. As categories became integrated and further data collection did not cause modifications of categories, but rather reinforced already-identified properties, we deemed the categories to be theoretically saturated.

Table 2. Categories and Code List

Category: definition	Code: definition	Code source*
Organization information services choreography (OISC) (contains 4 codes): corporate directives and structures that enable engagement, collaboration, and coordination to emerge among actors interacting with information services.	Vision**:** the foresight describing the way the organization coordinates the direction for integration of information services with organizational needs.	in vivo
	Strategy: the overall direction, policies, plans, targets, and performance assessment supporting an organization's information services-oriented vision.	in vivo
	Governance: the directives and structures that formalize processes, decision-rights, and responsibilities of the organization.	in vivo
	Resource allocation: the resource allocation model, including funding that fosters or constrains the organizational development of information services.	in vivo
Organization information services orchestration (OISO) (contains 3 codes): business and organizational activities that interact with each other in an information services-oriented environment.	Ongoing arrangements: the continuous configuration and reconfiguration of information services by users.	in vivo
	Plan selection: the selection of information service objectives by users and the formulation of tactical and operational plans to achieve those objectives.	in vivo
	Fostering participation: the organizational activities that help users discover, understand, and apply information services.	in vivo

Table 2. Categories and Code List (cont.)		
Category: definition	**Code: definition**	**Code source***
Organization information services instrumentation (OISI) (contains 3 codes): arrangement of information technologies and services employed and their individual properties.	Interfaces & standards: the principles, conventions, and conditions that guide and normalize the use of information services.	in vivo
	Development methods: the accepted approaches for system development and refinement.	in vivo
	IT architecture: the coordinated and coherent arrangement of information services that allow organizational units to focus on defining functionality independent of the technological infrastructure.	in vivo
External and internal forces (contains 5 codes): forces in the business environment that impact the decision making.	Political forces: the factors that are shaped by political actors who impact the information service decisions made by the organization.	Orlikowski and Baroudi (1991), Castells (2010)
	Economic forces: the factors that determine the state of competitive environment in which the organization operates.	Beniger (1986), Hansen and Wernerfelt (1989)
	Cultural forces: the forces that affect the basic values, behaviors, and preferences of the organization—all of which have an effect on decisions.	Pettigrew (1995), Pfeffer and Leblebici (1977)
	Demographic forces: the forces that derive from the changes in the characteristics of a population that affect how a business operates.	Pettigrew (1995), Bock, Zmud, Kim, and Lee (2005)
	Technological forces: the forces that have an impact on how the organization operates that are related to the technology used within the business environment.	Beniger (1986), Castells (2010)
Adaptive tension (contains 2 codes): a change dynamic as a system reacts to external pressure or improved self-organization.	Imposed tensions: the tensions that originate from an external domain or a technological innovation that disturb the equilibrium of a given domain.	Benbya and McKelvey (2006), Prigogine (1995)
	Improved fitness tensions: the tensions that create a drive toward improved effectiveness and alignment of processes and technologies.	Benbya and McKelvey (2006), Kaufaman (1993)
Requisite variety (contains 2 codes): ability to adjust to the requirements of a changing environment by achieving equivalent level of complexity.	Adaptive responses: the responses that improves the fit of the organization to its environment.	Boisot and McKelvey (2005)
	Maladaptive responses: the responses that do not provide adequate or appropriate adjustment to its environment.	Boisot and McKelvey (2005)

Table 2. Categories and Code List (cont.)

Category: definition	Code: definition	Code source*
Modular design (contains 2 codes): ability to reconfigure components by minimizing interdependencies among modules.	Modular design: the move toward autonomy and interdependence.	Simon (1962), Duncan (1995)
	Top-down design: the move toward top-down control and dependence.	Simon (1962), Duncan (1995)

Finally, several contacts at the research site reviewed the narrative, incident charts, and theoretical map, which allowed detailed discussions of the findings. In these discussions, different interpretations were provided by our contacts, which resulted in our increased understanding and enriched the analysis. The entire analysis was iterative and involved moving back and forth among the data, the existing literature, and the salient concepts that emerged at the research site.

4. Findings

Following the coevolutionary view to provide insight into the dynamic, multifaceted, and non-deterministic process of information services development, we present the findings in chronological order to explain "the temporal order in which a discrete set of events occurred, based on a story or historical narrative" (Huber & van de Ven, 1995, p. vii). We decompose this chronology into three successive phases—early years, exploration, and exploitation. We do not intend these phases to be a general sequence of the development of NOAA's information services. Instead, they provide a way of structuring the findings around a certain strategic continuity in the activities related to the development of information services that took place at NOAA in each period. As Langley (1999) recommends, this temporal structuring allows one to form comparative units of analysis that we use in Section 5, where we apply coevolution theory in analyzing the findings. Finally, we include our in vivo codes from Table 2, and indicate the specific actions and interactions between business actors and technology that influenced the information services development at NOAA in each phase.

4.1. Phase 1: The Early Years (2001-2005)

Since his appointment as the NOAA Administrator in 2001, retired Vice Admiral Conrad Lautenbacher often spoke about the need to integrate information from all of NOAA to address the complexity of the many environmental problems and to answer questions vital to addressing contemporary societal needs (vision). He spearheaded the first-ever Earth Observation Summit, which hosted ministerial-level representation from several dozen nations in Washington DC in July 2003. Through subsequent international summits and working groups, he encouraged world scientific and policy leaders to work toward a common goal of building a Global Earth Observation "system of systems" that would collect and disseminate data and information to stakeholders and decision makers for the benefit of all (strategy).

By the end of 2004, NOAA's top managers understood that ad hoc development would increase the difficulty in integrating information between programs and hamper NOAA's ability to address important multidisciplinary societal issues (vision). In addition, NOAA's 2005 Report to Congress stated that an important focus was to ensure that NOAA data was easily shared inside NOAA itself, with partner agencies, and with user communities (political force). Technical systems that enable data sharing became a priority as the NOAA 2005-2010 Strategic Plan noted:

> *No successful, societal response to environmental or ecological stress has ever been accomplished by a single agency or organization. We work with international institutions, state and federal agencies, tribes, local and regional governments, non-governmental organizations, educational institutions, and private business…*

In 2005, the NOAA Observing System Council, which was responsible for providing policy guidance for observing systems and data management, established the NOAA Data Management Committee (DMC) to explore ideas for providing easier and more cost-effective access to all of its archived data and information (governance). The DMC, in turn, hired a data management consultant to lead the exploration and established the Data Management Integration Team (DMIT) that included representatives from all NOAA line offices (resource allocation). The data management consultant recalled:

> *The administrator of NOAA emphasized how important data management issues were and how important it was that different data types could all be merged. I was hired by the DMC director to write out the plan. We put together a team with representatives of all NOAA organizations to develop the plan. At the end, we had a group of people who were well connected within their own communities, and had very good data management skills and knowledge across the various NOAA groups. There was a lot of value even in connecting these individuals... The time commitment for DMIT members had to be approved by their line supervisor who also set the level of commitment* [ongoing arrangement].

Table 3 presents the integrated view of the categories, the codes, and exemplar findings that contributed to our emerging understanding of the information services development at NOAA during this phase. These particular findings set the stage for interpreting subsequent phases of development by illustrating the goals, management interactions, and technical concerns present during the early years of information services development.

Table 3. Information Services Development at NOAA in the Early Years (2001-2005): Categories, Codes, and Findings

Categories	Codes	Illustrative data and quotes from the field
Corporate directives and structures that enable engagement, collaboration, and coordination	Vision	NOAA Administrator began to speak about the need to integrate information
	Strategy	NOAA hosted the Earth Observation Summit that led to the goal of building a Global Earth Observation System of Systems 2005 Report to Congress stated that an important focus was to ensure that NOAA data was easily shared within NOAA, with partner agencies, and with other communities
	Governance	DMC was established to explore ideas to improve data and information archival
	Resource allocation	Funds were assigned to hire a data management consultant and operational support "Time commitment for DMIT members had to be approved by their line supervisor who also set the level of commitment"
Business and organizational activities interaction	Ongoing arrangement	Every program was responsible for developing and maintaining its own required information systems
	Plan selection	
	Fostering participation	The perception was that there was no need to orchestrate these information systems and the business and organizational activities.

Table 3. Information Services Development at NOAA in the Early Years (2001-2005): Categories, Codes, and Findings (cont.)

Categories	Codes	Illustrative data and quotes from the field
Arrangement of information technologies and services	Interfaces & standards	Connectivity was limited and users needed to know where to access information. Data were available through incompatible interfaces and formats, and services from multiple centers could not be easily combined Lack of agreed-upon and implemented standards hampered the effective identification, acquisition, and correct use of relevant information.
	Development method	"I don't have time to try and think about how I can get all my [data] into standardized services… We develop the software needed to support our data needs" "There were interesting systems developed by different groups, but there was very poor integration of these efforts"
	IT architecture	Multiplicity of systems operated for different programs (creating inefficiencies, incompatibility, duplication of efforts, and high cost). Many of these systems were operated by partner agencies

4.2. Phase 2: Exploration Years (2005-2007)

This phase began with the DMIT exploring an approach of creating a NOAA-wide service-oriented architecture system (vision). As the lead consultant explained:

> *When we put the team together, we had meetings and teleconferences almost every two weeks for 2 years. We developed a comprehensive plan talking about the various issues that needed to be addressed at NOAA to make systems inter-operable. Service Oriented architecture was the approach that group recommended.*

The DMIT envisioned a NOAA Global Earth Observation Integrated Data Environment (GEO-IDE) "system of systems" that was to provide effective and efficient integration of NOAA's many legacy and quasi-independent systems that individually address diverse mandates in areas of resource management, weather forecasting, safe navigation, disaster response, and coastal mapping among others (vision). The goals were:

1) to take full advantage of the opportunity presented by Internet technology to make access to environmental data and information easy and effective and to provide access to digital documents over the Web, and

2) to improve efficiency and reduce cost by bridging the barriers between existing, independent "stove-pipe" systems and integrating the data management activities of all NOAA programs while avoiding a fully centralized approach.

In April 2006, the DMIT presented the GEO-IDE implementation plan. It selected a strategy "to continue operation of existing systems while gradually adopting and implementing NOAA-wide standards and improving integration through an evolutionary process of pilot projects and iterative improvement" (strategy). The plan provided specific actions, responsibilities, and milestones over a 10-year period and called for $2 million per year of operation funds, starting in January 2007 (resource allocation).

The GEO-IDE implementation plan, however, did not receive the requested resources (maladaptive response). The data management consultant commented:

> *We went into all this work, develop*[ed] *the plan*, [had] *it approved, but when the budget issues came along, it never received funding. The DMC didn't have budget authority. They took some of their own money to hire me and to pay for some travelling. However, they didn't have the level of funding for implementing the system as it was envisioned.*

There were very different interpretations of why the GEO-IDE implementation was not funded. A DMIT member, explained:

> *When you want to show that you are doing something, you just need to have a committee working together and writing a plan… Why put together a team to write a plan when there was no funding to support this plan? You can speculate that DMIT was that: the appearance of a plan without any money behind it* [plan selection].

A data administrator added:

> *The DMIT was tasked to do this by the NOAA administrator, so we were not concerned about creating a business case. We were given a task and we did it. We didn't know that we would have to sell this idea back to management* [plan selection].

These tensions reflect that NOAA's path-dependent history was not conducive to an information services design that was organizationally interoperable (cultural force), which the lead consultant noted:

> *We have to remember that NOAA was* [comprised of] *very different sets of organizations that were brought in together at the end of the* [1970s]. *These organizations didn't have a lot of synergy. So, the idea of making the data interoperable was not an easy sell.*

A DMC member added: "Part of the problem from the upper management perspective is that various communities that are getting data from NOAA are relatively happy with what they have. There [was] not a big push to provide inter-operable data."

Enduring attitudes were also seen in the development culture at NOAA (cultural force). For example, a scientist user explained his concern:

> *I don't have the time to try and think about how I can get all my* [data] *into standardized services. I don't see that as my job. I'm funded and I provide data to other NOAA offices, those are my main customers. We develop the software needed to support our data needs"* [maladaptive response].

Another DMIT member stated:

> *…people from the different units and talked about how hard the problem was, how much data we had, and how different our data files were. We tried to think about the system that would solve all the problems we had and how much money we would need. Endless meetings never generated something that could get us started. Everybody wanted the big system that solve*[d] *all the problems, and usually the users were not even involved* [maladaptive response].

Given the lack of dedicated resources for the GEO-IDE implementation, the data management consultant left NOAA (resource allocation). Yet another DMIT member provided his reflection on how his thinking evolved away from the planned top-down approach of this period:

> *…it is a mistake to try to visualize the end-state into a concrete state. You needed a more agile management approach that* [was] *more focused on process and less on the end-state.... A better idea became to have a system-of-systems* [approach] *capable of wrapping on the end-state. But, when you put a group of people in a committee, especially if they have technical inclination, they tend to be idealistic. What they ended up doing* [was] *analyzing the problem very thoughtfully from top to bottom, and trying to re-engineer processes that are working while replacing them with a new system, rather than building a system of systems that preserved the integrity of the existing systems* [top-down design].

Although with difficulties, members of the DMIT began working in their groups to provide services and move toward the concepts espoused by the GEO-IDE initiative (fostering participation). A NOAA systems architect explained his experience:

> *Although there is a lot of pressure to develop general services at NOAA, people work around them, because "we need it now". If we build tools that are appealing and easy for people to use* [interface & standard] *and demonstrate significant value over the old way of doing things, then that gets people to adopt it. This is almost the "build it and they will come" model, which is not always successful. However, I think there is also an education piece. For example, we have a* [prototype] *service that we developed. It was not perfect, but showed promise. However, because the users were not excited, it was never adopted* [development method].

A NOAA administrator suggested that "the transferring of these services to other NOAA groups for their usage has not been done well".

In Table 4, we present the categories, codes, and exemplar findings that contribute the growing understanding of the interactions, historical dependences, and adaptations that were occurring at NOAA during this phase. The table contains illustrative examples of the concepts in each of the organizational categories that evolved during the exploration years.

Table 4. Information Services Development at NOAA in the Exploration Years (2005-2007): Categories, Codes, and Findings

Categories	Codes	Illustrative data and quotes from the field
Corporate directives and structures that enable engagement, collaboration, and coordination	Vision	The initial vision was to create a NOAA-wide SOA system. By the end of this period, the vision became: "to have a system-of-systems [approach] capable of wrapping around existing systems."
	Strategy	The NOAA 2005-10 Strategic Plan recognized the importance of providing information, products, and services. A top-down, one-size-fits all services platform. "[We] ended up analyzing the problem very thoughtfully from top to bottom, and trying to re-engineering processes that are working while replacing them with a new system."
	Governance	The DMIT was responsible for the development of the GEO-IDE information services plan.
	Resource allocation	The DMIT initial implementation plan assumed dedicated personnel and staff and funding for $2M per year. This level of resources was not accepted by NOAA.

Table 4. Information Services Development at NOAA in the Exploration Years (2005-2007): Categories, Codes, and Findings (cont.)		
Categories	**Codes**	**Illustrative data and quotes from the field**
Business and organizational activities interaction	Ongoing arrangement Plan selection	DMIT was formed by people with very good data management skills and knowledge from across NOAA. They were also well connected to specific external user communities: “we had meetings and teleconferences almost every week for 2 years. We developed a comprehensive plan talking about the various issues that needed to be addressed at NOAA to make systems inter-operable.” DMIT developed an action plan based on a compelling technical case, but they were not concerned with the business case. “We tried to think about the system that would solve all the problems we had and how much money we would need.”
	Fostering participation	Initial reactions from users and technologists showed that the culture of NOAA was not conductive to a top-down SOA design: “Everybody wanted the big system that solved all the problems, and usually the users were not even involved.” Also: “Various communities that are getting data from NOAA are relatively happy with what they have. There [was] not a big push to provide inter-operable data.” Members of the DMIT began working within their groups to provide services and move toward the concepts espoused by GEO-IDE.
Arrangement of information technologies and services	Interfaces & standards	“Although there is a lot of pressure to develop general services at NOAA, people worked around them, because ‘we need it now’.” “We have a [prototype] service that we developed. It was not perfect, but showed promise. However, because users were not excited, it was not adopted.”
	Development method	DMIT members prototyped information services within their organizational units. However, “the transferring of these services to other NOAA groups for their usage has not been done well”. This was a “‘build it and they will come’ model, which is not always successful.”
	IT Architecture	The plan was to implement a NOAA-wide service-oriented architecture system.

4.3. Phase 3: Exploitation Years (2007-2010)

As Table 5 illustrates, the exploitation years (Phase 3) began with a change of the strategic intent in order to exploit (elaborate and deepen) existing capabilities to incrementally adopt information services at NOAA (ongoing arrangement). DMIT members kept trying to find the resources needed to make the GEO-IDE a reality as one of its members recalled: “There were some of us in the DMIT that lobbied every place we went that [information services] were important.” In this period, at least, a data management integration architect was hired to oversee the GEO-IDE implementation process (resource allocation). He recalled:

> *I knew it was going to be a challenge to bring this SOA mindset into the organization. Each one of the offices and individuals that we deal with at NOAA had their own local projects and individual requirements that they were trying to satisfy. You are trying to ask them to think about a different set of potential users.*

Rather than focusing on a top-down, one-size-fit-all services platform, the DMIT members began to search for solutions for NOAA users based on services (vision). Every new data program at NOAA began to include a "system of systems" and move toward the concepts espoused by the GEO-IDE initiative (plan selection). A member of the NOAA IT office explained:

> *DMIT members were involved in these projects. So, the principles and practices that were included in GEO-IDE were shared with all other projects. It is happening because of the people, not because* [of] *policies. We used collaboration tools for fostering voluntarism*. [The DMIT Chair] *reached* [out] *to people in the field and provided some funding to support pilot projects. We captured all those briefings and made them available in our wiki and blogs* [fostering participation; adaptive response].

The data management integration architect commented:

> *We are seeing that these autonomous efforts* [were] *leveraging what* [was] *going on in other areas. What we* [were] *trying to promote* [was] *the mindset of interoperable, autonomous systems. Instead of using a local system, people* [were] *developing services that* [could] *integrate with other NOAA services* [modular design].

During this period, the technical focus shifted to providing standardized access to data by way of web services that include improved analysis and visualization capabilities (development method). In addition, much greater dependence on new external technical standards ensued as IT developers in NOAA recognized that, as standards are adopted, the likelihood of other users adopting standards increases the overall value of the standard (interfaces & standards). A DMIT member reflected on his experience during this period:

> *I went around the country helping people in different regions to set up web services and* [use] *standards that had been put in place by NOAA… There was a lot of training and hand-holding that was required to get things working. Even now, three months later, I am still helping people. I am playing a tech-control role* [fostering participation; adaptive response]. *The beauty of the service approach came from the breakthrough of middleware software developed by Unidata that made it possible to connect the files to web services without anybody having to change their files… In the backend of its software was the middleware making the transformation and mapping the existing convention and format into the standard data model… I was acting as an interface between Unidata and the developers' community* [interfaces and standards].

The organizational structure of IT developers in NOAA also began to change. New coordinators/bridges were hired to help (resource allocation). A systems architect noted:

> *We had to look for a person that was technically savvy, but not a developer. Obviously, this person had to have well-developed people skills and be interested in diagnostic aspects… I think* [it] *is an important role and what I* [was] *looking for that position to do* [was] *not only* [diagnose] *the problems, but be more proactive about helping set standards* [interfaces and standards].

One of these newly hired coordinators/bridges explained:

> *When a scientist develops an application and it is ready for production, I shepherd him through that process to make sure that something is not missing, like the documentation or testing, or other labor intensive task. My role is mainly to build trust and collaboration. Everything else builds on these elements* [IT architecture].

In August 2009, the DMIT, at one of its meetings, decided to focus on one specific project. The Unified Access Framework (UAF) for gridded data would build momentum for implementing the GEO-IDE through a phased approach to data interoperability (modular design). It would:

1) engage data providers, users, and IT developers

2) leverage stable, proven solutions, and

3) have a high probability of demonstrable successes (development method). The project was launched in September 2009.

As the chair of DMIT explained:

> *The UAF project* [was] *a demonstration project targeted to a specific type of data* [and delivery approach]. *We* [were] *trying to improve the capabilities for* [a particular] *segment by presenting them to other potential users in other segments. Hopefully, once senior management sees* [the] *results, we'll get resources to improve. The idea of GEO-IDE is not trying to re-do everything, but trying to make the different pieces work together… and to make this effort visible to other programs and projects within NOAA* [adaptive response].

In addition, the DMIT chair lobbied for, and achieved, principle member status for NOAA in the Open Geospatial Consortium (OGC) that enabled it to have authority over the development, release, and adoption of standards (governance). Standards adoption at NOAA resulted in increased stability, alignment, and participation by creating reinforcing feedback, which he recalled:

> *OGC is about bringing standards so that data is shared. If you have services and data that follow standards, the probability of* [it] *being used for data sharing is higher....We have the first group, and the second group is looking around for influence to see if this is OK. So, we are seeing that everyone is accepting the standards. The top managers are getting accustomed to seeing the same requests.*

Table 5 summarizes the changes discussed above in relation to the categories and codes, and provides exemplar findings that increased our understanding of the third information services development phase at NOAA. Based on the data from these three phases, we revisit the development of services in light of the sensitizing lens of coevolution theory in Section 5.

Table 5. Information Services Development at NOAA in the Exploitation Years (2007-2010): Categories, Codes, and Findings

Categories	Codes	Illustrative data and quotes from the field
Corporate directives and structures that enable engagement, collaboration, and coordination	Vision	The GEO-IDE "system of systems" framework proposed by DMIT was accepted to guide NOAA's information services approach.
	Strategy	GEO-IDE strategy based on a cooperative integration style. Continuing operation of existing systems while gradually adopting services oriented standards through an evolutionary process of pilot projects and iterative improvements.
	Governance	DMC expanded its membership. New focus: organization-wide, end-to-end process for data management. NOAA became principal member of OGC, a non-profit, international, voluntary consensus standards organization.
	Resource allocation	Funding was provided to hire a data management integration architect, several system coordinators/bridges, and support pilot projects using the GEO-IDE principles.

Table 5. Information Services Development at NOAA in the Exploitation Years (2007-2010): Categories, Codes, and Findings (cont.)

Categories	Codes	Illustrative data and quotes from the field
Business and organizational activities interaction	Ongoing arrangement	DMIT kept lobbying for resources, which were not coming: "There were some of us in the DMIT that lobbied every place we went that [information services] were important."
	Plan selection	Every new data management program at NOAA began to include the idea of system of systems approach. "DMIT members involved in these projects. So the principles and practices that were included in GEO-IDE were shared…. It is happening because of the people, not because [of] policies." In particular, the unified access framework was accepted to be a demonstration project targeted to specific types of data.
	Fostering participation	"We used collaboration tools for fostering voluntarism." Some DMIT members were finding funding and supporting pilot projects while others were giving briefings to different groups. These briefings were captured and diffused using wiki and blogs. Rather than focusing on a top-down, one-size-fit-all services, DMIT members began to search for solutions to NOAA users based on services. "What we [were] trying to promote [was] the mindset of interoperable, autonomous systems. Instead of using a local system, people [were] developing services that [could] integrate with other NOAA services."
Arrangement of information technologies and services	Interfaces & standards	"The beauty of the service approach came from the breakthrough of middleware software developed by Unidata that made it possible to connect the files to web services…" "I went around the country helping people in different regions to set up web services and [use] standards that had been put in place by NOAA…"
	Development method	"There was a lot of training and hand-holding that was required to get things working... I was acting as an interface between Unidata and the developers' community."
	IT architecture	The structure of IT developers began to change. New coordinators were hired to help through the development, testing, and deployment of services.

5. Discussion: Revisiting the Development of Information Services at NOAA in Light of Coevolution Theory

On the basis of the case study findings, in this section, we broaden our discussion to introduce a coevolutionary view of information services development derived from NOAA's experience. We also offer propositions that can be used in future research to test the main features of the coevolutionary view advanced here. As the case study shows, the development of information services at NOAA was a process characterized by multiple change events and reflection, which required simultaneous adaptation at different levels. All these characteristics are fundamental in the coevolution of socio-technical systems. Thus, based on the salient concepts that emerged in the data analysis of the case study and the aspects of coevolution that have been considered important in the existing literature, we produced a coevolutionary view of information services development (as depicted in Figure 1). This view conforms to the premise that technology, human action, and institutional contexts interact and coevolve over time (Orlikowski & Robey, 1991). Depicted are three distinctive yet interdependent domains (theoretical categories):

1) Organization information services choreography (OISC), through which service interactions and collaborations are managed,

2) Organization information services orchestration (OISO), through which service processes are selected and interact, and

3) Organization information services instrumentation (OISI), by which services are developed and architected. These domains coevolved over time, and are instigated by three adaptive principles: adaptive tensions, requisite variety, and modular design.

Taken together, these three domains—OISC, OISO, and OISI—form the coevolutionary core of the organization information services ensemble, in which change in one domain at NOAA led to change in another. Cause-and-effect relationships are difficult to unravel because each domain's action reverberated through the intricate web of relationships that formed the information services ensemble (Mitleton-Kelly & Papaefthimiou, 2001). Furthermore, the information services development view advanced here builds on principles of adaptation (McKevely, 2004) that support the emergence of high-level features from interactions between individuals and between autonomous domains (Vidgen & Wang, 2009). At NOAA, adaptive tension, requisite variety, and modular design allowed for the framing of the process of adaptation and change of these domains not as a function of variables, but as a dynamic interplay of coevolving interactions, relationships, and effects. Finally, the view of information services development proposed here recognizes that the three domains and principles of adaptation affect, and are affected by, external environment forces. At NOAA, for example, the forces that affected and were affected by the information services development, as identified by the DMIT, are summarized in Table 6.

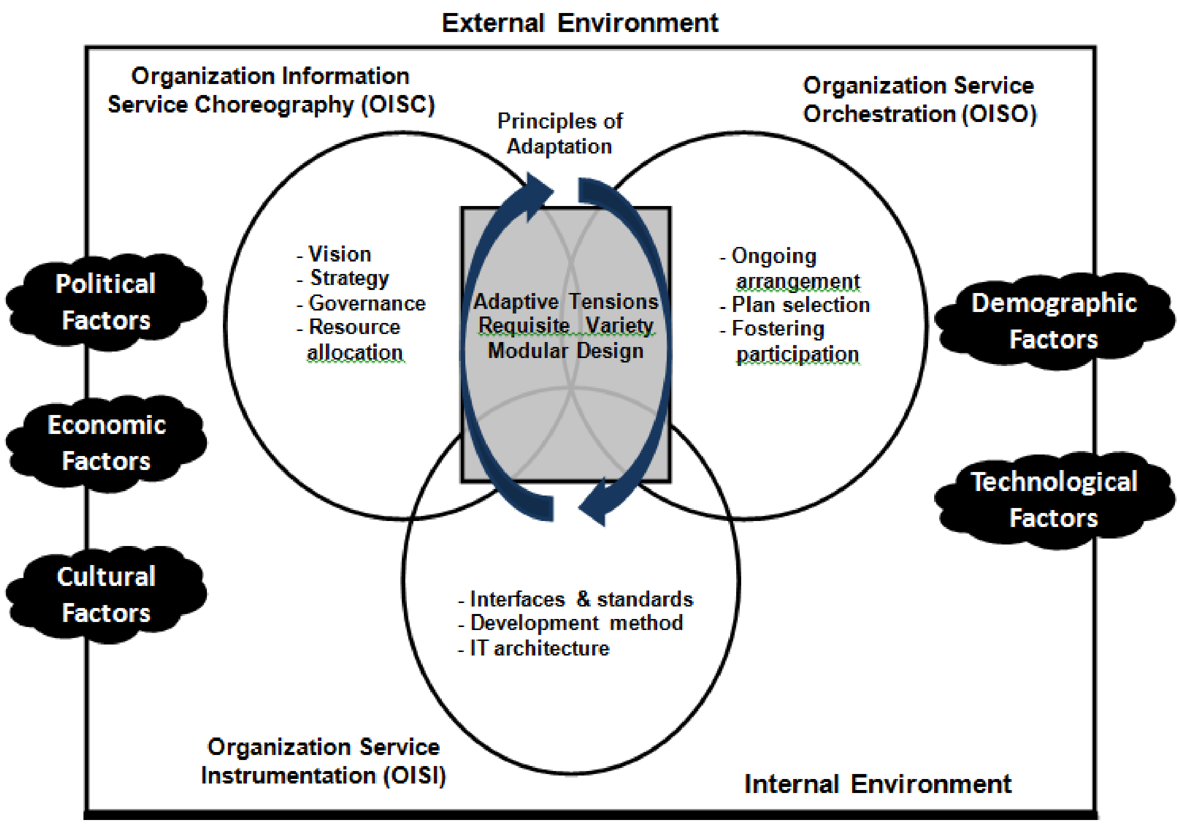

Figure 1. A View of Information Services Development Derived from NOAA's Experience Through the Lens of Coevolution Theory

Table 6. Most Significant Forces that Interacted During the Development of Information Services at NOAA

Forces	Description
Political	Recognition by the U.S. Congress that NOAA had to be ready to support increased requirements for cooperation and integration. NOAA became a principal member of OGC and was driven by the widespread and growing interest in information services' specifications.
Economic	As data volume grew exponentially, data diversity increased, and users' needs evolved, a more cost-effective access to NOAA data and information was needed.
Cultural	As interest in environmental issues increased, interest in environmental data stored at NOAA also increased.
Demographic	As users and tools became more computer savvy, additional requests for services provided by electronic libraries continued to increase.
Technological	In the ever-changing technology environment, volumes and diversity of data stored and distributed by NOAA continued to rapidly increase rapidly.

5.1. Domains that Formed the Coevolutionary Core of Information Services at NOAA

5.1.1. Organization Information Services Choreography

Starting on the left side of Figure 1, we describe the first domain, OISC. Choreography is the art of making structures in which movement occurs and the patterns of interaction among services and templates for sequences (or more structures) of interactions emerge (Treadwell, 2004). Web services choreography has been defined as a technical layer in the web services description language (Kavantzas, Burdett, & Ritzinger, 2004) for providing a technical explanation of service behavior, ordering rules, and information exchange. It has been typically associated with the public (globally visible) message exchanges, rules of interaction, and agreements that occur between multiple business process end-points, rather than a specific business process that is executed by a single party (Papazoglou, Traverso, Dustdar, Leymann, & Jramer, 2006). It is described from the perspective of all parties (common view) and defines the complementary observable behavior between participants in business process collaboration. Choreography offers a means by which the rules of participation and collaboration can be clearly defined and jointly agreed on. Choreography tracks the sequence of messages that may involve multiple actors and multiple sources, including customers, suppliers, and partners, where each actor involved in the process describes the part they play in the interaction and no one actor "owns" the conversation.

At the organizational level, OISC focuses on corporate directives and structures that enable an organization's information services engagement, collaboration, and coordination to emerge among the heterogeneous actors interacting with information services. As Figure 1 and Tables 3-5 show, the four concepts that we found to be important in this domain at NOAA were services vision, strategy, governance, and resources. A unified vision of the organization's information services is a critical foundation on which to define a coordinated direction for the integration of information services. Strategy encompasses the overall direction, policies, plans, targets, and performance assessment supporting the organization's information services-oriented vision. Due to the cross-organizational nature of end-to-end business processes composed from various information services, governance structures ensure that decision making processes extend to guarantee better ongoing alignment than those of "siloed" organizations. The resource allocation model, including funding, can pose obstacles or facilitate the evolution of organization-wide information services.

We argue first that the corporate directives and structures are key enablers/inhibitors of the process of information services development. Drawing on our definition of OISC and the empirical result derived from the NOAA case, we propose:

> **Proposition 1:** *Corporate directives and structures that have congruent service vision, strategy, governance, and resources, rather than those that focus solely on the technology, are more likely to achieve successful information services development by enabling engagement, collaboration, and coordination among heterogeneous actors*.

5.1.2. Organization Information Services Orchestration

Orchestration is the act of arranging a piece of music for an orchestra and assigning parts to the different musical instruments. In the same way, within organization processes, concurrent development must occur for "all services to be orchestrated in response to demands of specific usage models, such as those of business processes" (Rai and Sambamurthy, 2006, p. 330). Like a music composer, an information services user has to select the necessary information services and integrate information services in the ongoing creation and recreation of unique information systems.

Web services orchestration has received significant attention over the past five years, especially from the service oriented architecture community that uses it to describe how web services interact with each other at the message level (Peltz, 2003) and to explain an automated way to combine several web services together to achieve new functionality. In that domain, orchestration has been defined as "the ways in which business processes are constructed from web services and other business processes, and how these processes interact" (Treadwell, 2004, p. 4). An important distinction between web services orchestration and choreography is that orchestration is the interaction during execution, while choreography is the collaborative process describing the part that each web service plays in the potential interaction (Peltz, 2003).

Adapting this concept at the organizational level, OISO focuses on how business and organizational activities interact with each other in an information services-oriented environment. It is about dynamic, flexible, and adaptable execution of information services to meet the changing needs of an organization. It allows business and IT to speak the same language and dramatically reduces the effort needed to extract value using information services. Figure 1 and Tables 3-5 show the three concepts that we found to be important in this domain at NOAA: ongoing arrangement, plan selection, and fostering participation. Given that organization information services are easily configured by users, this drives ongoing arrangement by helping to eliminate less strategic information services, to abandon inefficient processes, to institute best practices embedded in information services, and to create new information services geared to support the organization's strategic and tactical business operations. Plan selection takes into account three fundamental aspects from the business side: business goals (objectives and desired outcomes), business context (current situation), and business events (dynamics) to create a plan. If a plan fails, a new, alternative plan is selected based on updated data. By doing this, OISO can be used in other plans that fit the current situation in real time, even when unplanned exceptions occur. Crucial for the emergence of new, potential solutions, and for continuous information services improvement, is fostering participation by helping users discover information services, understand their capabilities, and apply them.

We argue second that how business and organizational activities interact with each other will affect the process of information services development. Drawing on our definition of OISO and the empirical result derived from the NOAA case, we propose:

> **Proposition 2:** *The congruent orchestration of ongoing arrangement, selecting plan, and fostering participation, rather than simply supporting certain business and organizational interacting activities, is more likely to achieve successful information services development.*

5.1.3. Organization Information Services Instrumentation

Instrumentation refers to the particular combination of musical instruments employed in a composition, and to the properties of those instruments individually. It has also been used to describe services management tools in requirements analysis (Cox & Kreger, 2005). OISI is the organization of the information technologies and services employed and their individual properties. Information services-oriented technologies are often thought of as being the drivers in implementing information services in organizations. However, what often goes under the banner of information services technologies is primarily plumbing technology. Alternatively, the three concepts that we found to be important in this domain at NOAA, which Figure 1 and Tables 3-5 show, were interfaces and standards, development method, and IT architecture. Interfaces and standards are the principles, conventions, and conditions that guide and normalize the use of information services in the organization. Simple interfaces and standards are needed to allow for effective business process integration and interoperability with external business partners in addition to maximizing information services development efficiency. Rather than attempting to map out all the requirements before a system is developed or assuming that unanticipated needs will not arise once it is in operation, development methods focus on providing a path for the system to be developed over time and improved—rapidly and continuously. A coordinated and coherent IT architecture connects heterogeneous components and systems while providing multiple-channel access to information services, which thus allows organizational units to focus on defining information services functionality independent of the technological infrastructure.

We argue third that the particular combination of organizational information technologies and services used and their properties will influence the process of information services development. Drawing on our definition of OISI and the empirical result derived from the NOAA case, we propose:

Proposition 3: *The congruent combination of interfaces and standards, developing method, and IT architecture, rather than seeking the optimization of any of these elements by themselves, is more likely to successfully integrate the organization's information technologies and services.*

5.2. Adaptive Principles that Enabled the Coevolutionary Dynamics of Information Services at NOAA

Coevolution occurs when "populations of actors are forced to adapt to the changing context wrought by others' strategies in order to remain relatively fit" (Kim & Kaplan, 2005, p. 178). Until now, we show only the evolution of each of the three domains (as Tables 3-5 summarize). Now, we describe the adaptive principles that we observed at NOAA that acted as perturbations to one of these domains (i.e., OISC, OISO, and OISI), which, in turn, applied selection pressure in other domains: adaptive tension, requisite variety, and modular design.

5.2.1. Principle of Adaptive Tension

The principle of adaptive tension accounts for a change dynamic as a system reacts to external pressure or improved self-organization. At NOAA, this principle applied to the OISC, OISO, and OISI domains in explaining that the development of organization information services was not an event where a top-down set of requirements was translated into a service platform. Rather, it was a dynamic process full of internal and external pulls and pushes on the domains. Two forms of this principle are important in coevolution because entities (e.g., domains) evolve in response to changes in the environment. Imposed tensions (Prigogine, 1995) originate from other domains in the landscape or from technological innovations that disturb the equilibrium of organizational processes. Improved fitness tensions (Kauffman, 1993) create a drive toward improved effectiveness and alignment of processes and technologies due to feedback loops that reinforce the adaptation. A typical example is the adoption of technology standards that have a network effect that increases the likelihood of standards adoption by connected domains. Another form of tensions results from contradictions between what was durable or locked-in (Aanstead, 2011) and what could emerge through adaptation and selection by the organizational environment. Historical decisions regarding processes, technology, or attitudes are often path-dependent and may become reified and less amenable to change. A typical example would be historical decisions to implement specific legacy platforms that must be incorporated and aligned with future developments.

In the NOAA case, we see multiple tensions at work (Figure 2) that provide evidence of coevolutionary adaptations resulting from resolution of adaptive tensions. For instance, the OISC vision championed by the NOAA administrator from 2001-2005 imposed tensions (solid line arrows) on the OISO and OISI domains to better coordinate the collection and dissemination of geophysical and environmental data. The existing equilibrium processes would not fulfill the new vision requiring adaptations to the processes of dissemination. This motivated the strategic initiative to host the first-ever Earth Observation Summit aimed to improve organizational alignment and coordination with external agencies (arrow 1). Furthermore, this tension also motivated new governance structures in the OISC domain evidenced by the creation of the DMC, which in turn established the DMIT and allocated resources to hire a data management consultant (arrow 2).

From 2005-2007, the DMIT's initial technology selection (OISO domain) called for the adoption of a unique service-oriented platform that would enhance the provision of information for the entire NOAA organization (arrow 3). That technology plan selection created an improved fitness tension (dashed line arrows) that motivated the adoption of a organization-wide SOA plan on the OISC level (arrow 4) and the assignment of resources, including money and fulltime positions dedicated to the GEO-IDE adoption (which did not materialize) (arrow 5). It also imposed tensions on the existing OISI development methods to adopt new interfaces and standards (arrow 6). These tensions increased among scientists as they "worked around them [information services], because we [NOAA scientists] need it now". The many latent tensions described here surfaced the problem of whether the implementation of a top-down, one-size-fits-all system could ever be successfully built and implemented.

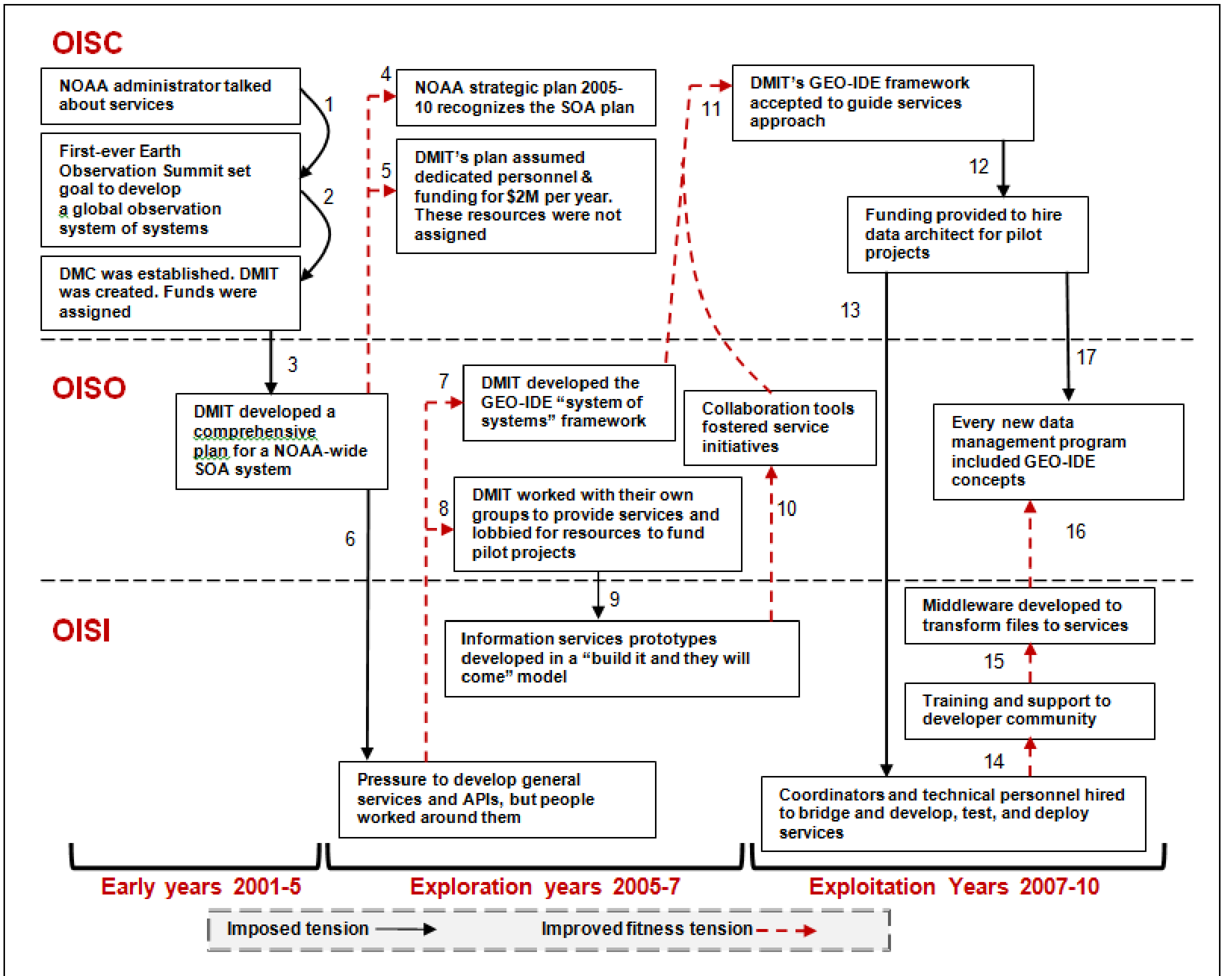

Figure 2. Critical Incident Chart of Adaptive Tensions at NOAA (from Case Data)

In contrast, the approach the DMIT followed in developing the GEO-IDE "system of systems" framework provides examples of the successful "ratcheting up" engendered by improved fitness tensions. The DMIT members became cognizant of the inherent vulnerability of a planned approach, which would create "confrontational" relationships with scientists (arrow 7). The DMIT proposed an implementation spiral that minimized the "you have to do it this way" approach. Instead, the DMIT worked with data users in their own working groups to provide information services (arrow 8). Prototype information services, standardized information services interfaces, and collaboration tools were introduced (arrow 9). Using a development spiral, the DMIT worked with data users to define what they needed, facilitate cooperation and internal best practices referrals, and keep managers up-to-date with a changing environment (10). All these efforts generated tensions that motivated the organization to accept the GEO-IDE framework as the institutional guideline to develop information services (arrow 11) and provide funding to hire a data architect to oversee the development of pilot projects (arrow 12). Coordinators and technical personnel were hired to develop, test, and deploy services (arrow 13). Training and support was offered to the developers' community (arrow 14). At the same time, technical support was provided to transform traditional files to information services (arrow 15). All these efforts resulted in the movement of the various programs and units within NOAA towards adopting the GEO-IDE concepts, while the expectations of the scientists and the services developers were aligned with the level of resources available (arrows 16 and 17).

The coevolution resulting from adaptive tensions reveals that information services development is not a simple matter of top-down development aligned with organizational needs. Historical path dependencies, cultural attitudes, and decision timing can create durability that is not susceptible to change. At NOAA, the coevolution of OISC, OISO, and OISI occurred in response to adaptive tensions acting through the interactions among overlapping sets of individual and group perspectives as the GEO-IDE initiative developed and diffused at multiple levels of the organization. Drawing on these observations, we propose:

Proposition 4: *Managerial actions that impose tensions on OISC, OISO and OISI rather than solely impose tensions on one of these domains are more likely to promote successful information services development by motivating a multilevel move toward more experimentation, entrepreneurship, and innovation.*

Proposition 5: *Managerial actions that make fitness tensions visible at OISC, OISO and OISI rather than only in one of these domains are more likely to promote successful information services development by creating reinforcing feedback that sparks coevolutionary dynamics between the three domains.*

5.2.2. Principle of Requisite Variety

This principle allows us to analyze the evolving complexity of the information services development at NOAA. The principle builds from Ashby's (1956) "law of requisite variety", which Boisot and McKelvey (2005) update to the "law of requisite complexity", which states that, in order to remain viable, a system needs to generate the same degree of internal complexity as the external complexity it faces in its environment. In other words, the larger the variety of pathways generated in the system, the more adaptive the system will need to be to forces in the system and the landscape (Hanseth & Lyytinen, 2010; Axelrod & Cohen, 1999).

During the 2005-2007 period, the NOAA case shows that scientists did not understand why they should spend their time and energy on developing and learning information services when they had the IT systems they needed for their specific projects. It did not make much "energy-use" sense for systems developers to put time and effort into bringing new ideas into an organization filled with users who preferred their own custom-built "stovepipe" systems. Additionally, it was difficult for NOAA employees to understand the benefits of integrating systems. The DMIT members soon realized that they were putting time, energy, and money into information systems services that were misaligned, and that it was not realistic to design an organization-wide, service-oriented platform with the sufficient up-front complexity to respond to the dynamic environment and the multiple forms of data, programs, users, and partners. This aligns with the realization that organizations do not want to pay for any more internal capabilities than necessary, and do not want to learn about any more external opportunities than necessary (Benbya & McKelvey, 2006). This is also consistent with the least-effort theory (Zipf, 1949) that applies to firms wanting to be efficient in matching internal with external opportunities—there is a cost to increasing internal options and a cost to reducing external options to only the critically important ones.

During the 2007-2010 period, however, DMIT members realized that the NOAA data environment was more aligned with the concept of orchestrating the interactions of many systems rather than creating a monolithic system for all users and functions. This view was shaped as consisting of many systems evolving toward "trade-off" points resulting in a "system of systems". It became essential to develop information services able to coevolve and generate sufficient complexity as needed. In other words, the feedback derived from the scientists and the various new programs adopting the GEO-IDE principles was positive, and suggested a development process of information services based on the structural assembly of existing systems that could allow divergences. This approach facilitated the formation of a more complex and encompassing governance at the OISC. At the OISO level, the process created the demand for more complex coordination mechanisms and the adoption and maintenance of repositories like wikis and blogs, all intended to stimulate emergent information services initiatives. At the OISI IT architecture level, changes were required in the skills set of the technical people. "Coordinators" and "bridges" were hired to accommodate the complexity that began to appear in developing, testing, and deploying information services. We argue that a development strategy that accommodates changes and evolves in response to environmental perturbations and feedback is more likely to succeed than a fixed strategy that does not change or interact with internal and external elements. Accordingly, we propose:

> **Proposition 6:** *Developing information services that evolve and provide adaptive responses are more likely to achieve success because they are able to respond to dynamic and unpredictable perturbations of the environment quicker than those designed with upfront complexity.*

5.2.3. Principle of Modular Design

This principle follows Simon's (1962) argument that complex systems that are hierarchical, but consist of subunits that are mostly independent from top-down control, tend to evolve efficiently toward stable, self-generating configurations. In information systems research, modularity has been recognized as the ability to reconfigure (add, modify, or remove) technology components by minimizing interdependencies among modules, and has been considered a key dimension in IS flexibility (Duncan, 1995). A new, higher degree of modularity consequently means a greater speed in developing new applications, or modifying existing ones. It is important to be aware that, although modular design is useful for flexibility and development options, as the number of modules increases, the number of connections, the connection costs, and the complexity also increases.

At NOAA, the principle of modular design was present as a series of big and small coevolutionary moves made over time by individuals and groups across OISC, OISO, and OISI balancing autonomy and interdependence. Prior to 2005, there was considerable sub-unit autonomy that led to misalignment because the parts were unaware of each other. At that time, each organizational unit and program in NOAA had full authority and autonomy to make decisions about their information systems without being required to coordinate or seek approval from other levels.

During the 2005-2007 period, the effort of trying to automate the existing practices by seeking a predefined, one-size-fits-all services platform became an overwhelming task and the design became too big, monolithic, and unresponsive to the various types of data, user communities, and changing conditions at the various organizational levels. During the 2007-2010 period, the DMIT members dynamically adjusted their approach and developed a more modular system. Different projects began to adopt the GEO-IDE principles and the DMIT members focused on prototyping these principles in the UAF project. Thus, a mutually reinforcing pattern of evolving and tightly aligned services orientation initiatives was created. Following these observations, we propose:

> **Proposition 7:** *Information services are more likely to achieve success if they are designed toward autonomy (modular design) rather than toward top-down control because they are able to adapt more quickly in response to dynamic changes.*

6. Limitations

This study is based on a single case study, and one could argue that it has a limited scope for generalization, at least in a traditional sense. As Lee and Baskerville (2003) discuss, however, we generalized thick descriptions to concepts, specific implications, and rich insights, and thus provide generalizability through theory (Walsham, 1993; Klein & Myers, 1999). By clarifying the context and understanding the principles that contributed to the process of information services development that unfolded at NOAA, others, guided by the coevolutionary perspective, may adapt these insights, principles, and propositions to a different context. We do not claim that the ensemble of domains and principles of adaptation presented in this paper are exhaustive. Further research is clearly needed to test the applicability of this information services view to other contexts because not all developments of information services in organizations involve the same set of adaption principles and actions.

7. Implications and Conclusions

This study increases our understanding of the open-boundary, dynamic, and multilevel processes of information services development, and develops theoretical constructs that can inform researchers and practitioners. We focused on two research questions:

1) What were the critical domains and interactions associated with the emerging process of information service development?

2) How did information services at NOAA evolve over time?

With this research, we make three main contributions. First, we apply coevolution theory as a general logic for understanding (not for describing events or testing theory through predictions) the dynamic process of organizational information services development by focusing on longitudinal time frames, multidirectional causality, linearity, positive feedback, path dependence, and the inclusion of multilevel, historical, and contextual information (Lewin & Volberda, 1999). This study is significant in that it's the first in-depth empirical study of the coevolution of the socio-technical elements of information services development over time. This research moves away from the traditional approach to service design as a rationally planned and controlled process, which assumes alignment as an automatic outcome. The paper's shift in focus is based on the evidence that this is an emergent, dynamic process that includes social, technical, and organizational elements. The processes that influence changes in elements of the systems are themselves emergent and the agents are heterogeneous with changing needs and requirements. Furthermore, complex interactions occur in a multi-dimensional space that not only includes the technical dimension, but also social, organizational, physical, political, and economic areas that interact, influence each other, co-evolve, and constantly change that space of interaction.

As a second contribution, by analyzing the rich data of NOAA's experience, this study proposes a coevolutionary view of information services development and formulated propositions that have the potential to inform future research by focusing simultaneously on two critical dimensions: what changes, and the process of how it changes. The view advanced here presents three distinctive yet interdependent domains (what changes):

1) Services choreography, through which services interactions and collaborations are managed

2) Services orchestration, through which services processes are selected and interact, and

3) Services instrumentation, by which services are developed and architected.

The coevolutionary view captures the mutual forces and resultant changes over time in the development of information services in organizations (how it changes), not simply as a matter of alignment between the organization and the technology, but as an interplay between coevolving domains and interactions. This study advances coevolution theory by specifying three adaptive principles: adaptive tensions, requisite variety, and modular design as mechanisms by which change occurs. These tensions became particularly visible as new personnel and a new development vision were brought into NOAA. The principle of requisite variety resulted in coevolution between the technically-oriented OISI domain and the OISO domain such that the orchestration of a "system of systems" provided the strongest adaptive alignment in the system and from the landscape. Finally, modular design is well established as a developmental goal, and this study reveals that, as a coevolutionary principle, modularity plays an important role in balancing maximizing services flexibility and management of connections, connection costs, and complexity. As modules were prototyped, users at multiple organizational levels of NOAA provided feedback, creating reinforcing patterns of evolving technology that were tightly aligned with evolving departmental goals.

Although these principles are not exhaustive, this study provides strong empirical evidence of the degree to which coevolutionary principles affect development and serve to expand and provide detail regarding coevolutionary processes. For example, the coevolutionary development of information services can be considered in light of complex adaptive system (CAS) (Vidgen & Wang, 2006; Choi, Dooley, & Rungtusanatham, 2001; Peppard & Breu, 2003). That is, coevolutionary systems are comprised of distributed, multi-actor processes, tensions of change induced by external forces and by increasing fitness between stability and emergence, and an integration of alignment and development of both technology and organizational structures. This analytic consideration reflects the quasi-equilibrium and multi-actor relationships present in any system development project (Vidgen & Wang, 2006; Hanseth & Lyytinen, 2010). Our study focuses on "what" changed and the process of "how" it changed over time to better understand the process of information services development. Future research is needed to understand the "why". Why did the process change in the way that it did, and what constraints limit change? Why could it not have been otherwise? This calls for applying other complexity principles that could offer complementary explanations of the coevolutionary process, which would thus expand the ideas presented here and building toward a rich picture of coevolutionary development processes.

As a third contribution, the critical domains and interactions associated with information services that this research identifies offer new ways of practically managing the emerging process of their development in organizations. Recognizing the tensions between organizational entities and evolutionary adaptions is likely to be more effective than traditional information systems development approaches that are premised on a rationally planned and controlled development process through which alignment is automatically obtained (Hanseth & Lyytinen, 2010). As we have seen, this is a particularly important issue given the increasingly dynamic organizational world and the emerging vision to connect people, places, and things through information services enabled by a heterogeneous set of network technologies. For practitioners, this study provides useful insights into how to understand, manage, and participate in the broad array of information services development environments to which an organization may be exposed (e.g., enterprise level, open source, and crowd-sourced). These environments are composed of multiple, dynamic agents, and our application of a coevolutionary analysis highlights the improvisational adaptations that can resolve development tensions across development boundaries. The coevolutionary view of information services development presented here provides the basis for a constructive and penetrating dialogue among practitioners and a set of normative suggestions derived from coevolutionary adaptation principles (summarized in Table 7) that provide guidance in these dynamic processes. The coevolutionary perspective sensitizes practitioners to the unfolding events and tensions that occur during technology development and alignment, where monitoring events enables the distribution of authority and resources allocation and provides guidance for technology alignments and change management.

Table 7. Strategies and Tactics for Practitioners in the Development of Information Services	
Adaptation principle	**Normative suggestions for managers**
Adaptive tension	- Be aware that developing information services is a dynamic process full of contradictions generated by tensions imposed on the system and by tensions that arrive from improved fitness of the system. Thus, the manager's role is to identify and/or impose tensions when and where needed. - Impose tensions at OISC, OISO, or OISI to motivate the organization toward more experimentation, entrepreneurship, and innovation. - Identify tensions showing up as drives from improved fitness, make them visible, and use them to set off reinforcing feedback that sparks coevolutionary dynamics between OISC, OISO, and OISI.
Requisite variety	- Be aware that it is difficult and costly to map out all the requirements before the development of information services starts. Unanticipated needs will arise once information services are in operation. In addition, persuading people to use and "own" information services after they are implemented requires incentive structures. - Do not attempt to create information services with up-front complexity to respond to all organizational needs (the "perfect" choreography set of corporate directives and structures, the "true" orchestration set of business and administrative activities interacting with information services, and the "complete" information services platform). - Focus on creating and evolving sufficient complexity in your information services to respond to the dynamic, complex environment.
Modular design	- Be aware that developing information services is a process of coevolution among a set of interdependent domains (OISO, OISC and OISI) in which top-down control and bottom-up autonomy influences are "mangled" in an inseparable manner. - Take advantage of a modular design as means to manage information services complexity. Modular design is useful for flexibility, but imposes connection costs. - Manage the critical edge of staying at the most efficient amount of modularity and inter-module connections. In one hand, if modules are too large, they become unwieldy and unresponsive monoliths. On the other hand, as modules increase, the number or inter-module connections and connection costs increase.

The NOAA case study underscores that tensions imposed by change are inevitable, and that coevolution of organizational entities is continuous and expected when developing an aligned ensemble of information services. Given the coevolution of the three domains identified here, and the ongoing exchange that took place among and in them, effective management requires balancing choices made across all three domains—a dilemma that managers face in balancing what needs to be controlled against what will emerge. This situation will differ for each organization and for different parts of the organization, as we note earlier. Managers need to develop strategies and tactics to cope with anticipated and emergent change resulting from adaptive principles (adaptive tensions, requisite variety, and modular design) that occur during information services development.

Acknowledgements

We greatly appreciate the extensive access to personnel and information provided by the host research institution, NOAA. We especially thank Ted Habermann, Director of NOAA's Earth Science Group, as well as senior editor Michael Barrett and the anonymous associate editor and reviewers for their thoughtful criticisms and helpful comments.

References

Aanestad, M. (2011). Information systems innovation research: Between novel futures and durable presents. In M. Chiasson, O. Henfridsson, H. Karsten, & J. DeGross (Eds.), *Researching the future in information systems* (pp. 27-41). Truku, FI: Springer.

Alter, S. (2009). Mapping the domain of service science. *Proceedings of the 2009 Americas Conference on Information Systems.*

Anderson, P. (1999). Complexity theory and organization science. *Organization Science, 10*(3), 216-232.

Ashby, W.R. (1956). *An introduction to cybernetics*. London: Chapman & Hall.

Axelrod, R.M., & Cohen, M. D. (1999). *Harnessing complexity: Organizational implications of a scientific frontier.* New York: Free Press.

Barnett, W. P., & Hansen, M. T. (1996). The red queen in organizational evolution. *Strategic Management Journal*, *17*, 139-157.

Baum, J. A. C. (1999). Organizational Ecology. In R. Steward, C. H. Hardy, & W. R. Nord (Eds.), Variation in organization science: In honor of Donald T. Campbell (pp. 113-135). London: Sage.

Benbasat, I., Goldstein, D. K., & Mead, M. (1987). The case research strategy in studies of information systems. *MIS Quarterly*, *11*(3), 369-386.

Benbya, H., & McKelvey, W. (2006). Using coevolutionary and complexity theories to improve IS alignment: A multi-level approach. *Journal of Information Technology, 21*(4), 284-298.

Beniger, J. R. (1986). *The control revolution: technological and economic origins of the information society.* Cambridge, MA: Harvard University Press.

Bergman, M., King, J., & Lyytinen, K. (2002). Large-scale requirement analysis revisited. *Requirements Engineering, 7*, 152-71.

Bieberstein, N., Bose, S., Fiammante, M., & Shah, R. (2006). *Service-oriented architecture compass: Business value, planning, and enterprise roadmap.* Upper Saddle River, NJ: Pearson.

Bieberstein, N., Bose, L., Walker, A., & Lynch, A. (2001). Impact of service-oriented architecture on enterprise systems, organizational structures, and individuals. IBM Systems Journal, 44(4), 691-708.

Bock, G., Zmud, R. W., Kim, Y., & Lee, J. (2005). Behavioral intention formation in knowledge sharing: Examining the roles of extrinsic motivators, social-psychological forces, and organizational climate. *MIS Quarterly*, *29*(1), 87-111.

Boisot, M., & McKelvey, B. (2005). Speeding up strategic foresight in a dangerous, complex world. In G. G. S. Suder (Ed.), *Corporate strategies under international terrorism and adversity* (pp. 20-37). Cheltenham: Edward Elgar.

Calori, R., Lubatkin, M., Very, P., & Veiga, J. F. (1997). Modeling the origins of nationally bounded administrative heritages: A historical institutional analysis of French and British firms. *Organization Science, 8*(6), 681-696.

Castells, M. (2010). *The rise of the network society: The information age: Economy, society, and culture* (Vol. 1, 2nd edn.). Malden, MA: Willey-Blackwell.

Casti, J. (1994). *Complexification: Explaining a paradoxical world though the science of surprise*. New York: HarperCollins.

Choi, T., Dooley, K., & Rungtusanatham, M. (2001). Supply networks and complex adaptive systems: Control versus emergence. *Journal of Operations Management, 19*(3), 351–366.

Ciborra, C. (1994). The grassroots of IT and strategy. In C. Ciborra & T. Jelessi (Eds.), *Strategic information systems: A European perspective* (pp. 3-24). Chichester, UK: John Wiley & Sons.

Ciborra, C. (2002). *The labyrinths of information: Challenging the wisdom of systems*. Oxford, UK: Oxford University Press.

Cohen, J., & Steward, I. (1994). *The collapse of chaos: Discovering simplicity in a complex world*. New York: Viking.

Coff, R. (2010). The coevolution of rent appropriation and capability development. *Strategic Management Journal*, *3*(1), 711-733.

Cox, D., & Kreger, H. (2005). Management of the service-oriented-architecture life cycle. *IBM Systems Journal*, *44*(4), 709-726.

Dijksterhuis, M. S., & van den Bosch, F. A. J. (1999). Where do new organizational forms come from? Management logistics as course of coevolution. *Organization Science, 10*(5), 569-582.

Dooley, K. J. (1997). A complex adaptive model of organization change. *Nonlinear Dynamics, Psychology, and Life Science*, *2*(1), 69-97.

Duncan, N. B. (1995). Capturing flexibility of information technology infrastructure: A study of resource characteristics and their measure. *Journal of Management Information Systems, 12*(2), 37-57.
Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review*, *14*(4), 532-550.
Eisenhardt, K. M., & Galunic, D. C. (2000). Coevolving. *Harvard Business Review, 78*(1), 91-101.
Germonprez, M., Hovorka, D., & Collopy, F. (2007). A theory of tailorable technology design. *Journal of the Association for Information Systems*, *8*(6), 315-367.
Germonprez, M., Hovorka, D., & Gal, U. (2011). Secondary design: A case of behavioral design research. *Journal of the Association for Information Systems, 12*(10), 662-683.
Glaser, B. G. (1978). *Theoretical sensitivity*. Mill Valley, CA: Sociology Press.
Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research.* New York: Aldine Publishing Company.
Golden, B. R. (1992). The past is the past—or is it? The use of retrospective accounts as indicators of past strategy. *Academy of Management, 35*(4), 848-860.
Gregor, S. (2006). The nature of theory in information systems. *MIS Quarterly, 30*(3), 611-642.
Gregor, S., & Jones, D. (2007). The anatomy of a design theory. *Journal of the Association for Information Systems, 8*(5), 312-335.
Guastello, S. (1995). *Chaos, catastrophe, and human affairs*. Mahwah, NJ: Erlbaum.
Gurbaxani, V., Melville, N., & Kraemer, K. (2000). The production of information services: A firm-level analysis of information systems budgets. *Information Systems Research, 11*(2), 159-176.
Hansen, G., & Wernerfelt, B. (1989). Determinants of firm performance: The relative importance of economic and organizational factors. *Strategic Management Journal, 10*, 399-411.
Hanseth, O., & Lyytinen, K. (2010). Design theory for dynamic complexity in information infrastructures: The case of building Internet. *Journal of Information Technology*, *25*(1), 1-19.
Hirschheim, R., Welke, R., & Schwarz, A. (2010). Service-oriented architecture: Myths, realities, and a maturity model. *MISQ Executive*, *9*(1), 37-48.
Hovorka, D. S. (2005). *Functional explanation in information systems.* Paper presented at the Proceedings of the 11th Americas Conference on Information Systems, Omaha, NE.
Huber, G., & van de Ven, A. (Eds.). (1995). *Longitudinal field research methods*. Thousand Oaks, CA: Sage.
Huygens, M., Baden-Fuller, C., van den Bosch, F. A. J., & Volberda, H. W. (2001). Co-evolution of firm capabilities and industry competition: Investigating the music industry, 1877-1997. *Organization Studies, 22*(6), 971-1011.
Jones, M. R. (1999). Information systems and the double mangle: Steering a course between the scylla of embedded structure and the charybdis of strong symmetry. In T. Larsen, L. Levine, & J. DeGross (Eds.), *Information systems: Current issues and future challenges* (pp. 287-302). Luxemburg, Austria: IFIP.
Kallinikos, J. (2004). Farewell to constructivism: Technology and context-embedded action. In C. Avgerou, C. Ciborra, & F. Land (Eds.), *The social study of information and communication technology* (pp. 140-161). New York: Oxford University Press.
Kauffman, S. A. (1993). The origins of order: Self-organizing and selection in evolution. Oxford, UK: Oxford University Press.
Kavantzas, N., Burdett, D., & Ritzinger, G. (2004). *Web services choreography description language version 1.0.* Retrieved from http://www.w3.org/TR/2004/WD-ws-cdl-10-20040427/
Kieser, A. (1989). Organizational, institutional, and societal evolution: Medieval craft guilds and the genesis of formal organizations. *Administrative Science Quarterly, 34*(4), 540-564.
Kim, R., & Kaplan, S. (2005). *Co-evolution in information systems engagement: Exploration, ambiguity and the emergence of order*. Paper presented at the 2005 Proceedings of Action in Language, Organizations and Information Systems, Limerick, Ireland.
Kirsch, L. J. (2004). Deploying common systems globally: The dynamics of control. *Information Systems Research, 15*(4), 374-395.
Klein, H. K., & Myers, M. D. (1999). A set of principles for conducting and evaluating interpretative field studies in information systems. *MIS Quarterly*, *23*(1), 67-93.
Konana, P., Gupta, A., & Whinston, A. (2000). Integrating user preferences and real-time workloads in information services. *Information Systems Research, 11*(2), 177-196.
Koza, M. P., & Lewin, A. Y. (1998). The coevolution of strategic alliances. *Organization Science, 9*(3), 255-264.

Koza, M. P., & Lewin, A. Y. (1999). The coevolution of network alliances: A longitudinal analysis of an international professional service network. *Organization Science, 10*(5), 638-653.

Lahiri, S., & Keia, B. L. (2010). Co-evolution of institutional and organizational factors in explaining offshore outsourcing. *International Business Review*, *20*(3), 252-263.

Langley, A. (1999). Strategies for theorizing from process data. *The Academy of Management Review*, *24*(4), 691-710.

Lee, A., & Baskerville, R. (2003). Generalizing generalizability in information systems research. *Information Systems Research*, *14*(3), 221-243.

Lewin, A. Y., & Long, C. P. (1999). The coevolution of new organizational forms. *Organization Science*, *10*(5), 535-550.

Lewin, A. Y., & Volberda, H. W. (1999). A framework for research on strategy and new organizational forms. *Organization Science, 10*(5), 519-534.

Lewin, A. Y., Carroll, T., & Long, C. P. (1999). The coevolution of new organization forms. *Organization Science, 10*(5), 535-550.

Lu, Y., & Ramamurthy, K. (2011). Understanding the link between information technology capability and organizational agility: An empirical examination. *MIS Quarterly*, *35*(4), 931-954.

Madill, A., Jordan, A., & Shirley, C. (2000). Objectivity and reliability in qualitative analysis: Realist, contextualist and radical constructionist epistemologies. *British Journal of Psychology*, *91*(1) 1-20.

McKelvey, W. (1997). Quasi-natural organization science. *Organization Science*, *8*(4), 352-380.

McKelvey, W. (1999). Avoiding complexity catastrophe in coevolutionary pockets: Strategies for rugged landscapes. *Organization Science*, *10*(3), 294-321.

McKelvey, W. (2004). *1st principles of efficacious adaptation* (Working paper). Los Angeles, CA: UCLA Anderson School of Management.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: A sourcebook of new methods.* Beverly Hills, CA: Sage.

Miller, C. C. (1997). Retrospective reports in organizational research: A reexamination of recent evidence. *Academy of Management*, *40*(1), 189-204.

Mitleton-Kelly, E., & Papaefthimiou, M. C. (2001). Co-evolution and an enabling infrastructure: A solution to legacy? In P. Henderson (Ed.), *Systems engineering for business process change* (pp. 164-181). New York: Springer-Verlag.

Nissen, M. E., & Jin Y. (2007). Co-evolution and co-design of agile information systems through agent-based modeling. In K. C. de Souza (Ed.), *Agile information systems: Conceptualization, construction, and management* (pp. 266-284). Burlington, MA: Butterworth Heinemann.

Orlikowski, W. J. (1996). Improvising organizational transformation over time: A situated change perspective. *Information Systems Research*, *7*(1), 63-92.

Orlikowski, W. J., & Baroudi, J. (1991). Studying information technology in organizations: Research approaches and assumptions. *Information Systems Research*, *2*(1), 1-28.

Orlikowski, W. J., & Hofman, J. D. (1997). An improvisational model for change management: The case of groupware technologies. *Sloan Management Review*, *38*(2), 11-21.

Orlikowski, W. J., & Robey, D. (1991). Information technology and the structuring of organizations. *Information Systems Research, 2*(2), 143-169.

Orlikowski, W. J., & Scott, S. (2008). Chapter 10: Sociomateriality: Challenging the separation of technology, work and organizations. (Working Paper Series). *The Academy of Management Annals*, *2*(1), 433-474.

Pacheco, D. F., York, J. G., Dean, T. J., & Sarasvathy, S. D. (2010). The coevolution of institutional entrepreneurship: A tale of two theories. *Journal of Management*, *36*(4), 974-1010.

Pacheco, D. F., York, J. G., & Hargrave, T. J. (2011). The coevolution of industries, social movements and institutions: The case of wind power*. Proceedings of the Academy of Management*, *1*, 1-6.

Papazoglou, M. P., Traverso, P., Dustdar, S., Leymann, F., & Kramer, B. J. (2006). Service-oriented computing: A research roadmap. In F. Cubera, B. J. Kraemer, & M. P. Papazoglou (Eds.), *Service oriented computing*. Germany: Schloss Dagstuhl.

Patton, M. Q. (1990). *Qualitative evaluation and research methods* (2nd edn.). Thousand Oaks, CA: Sage.

Peltz, C. (2003). Web services orchestration and choreography. *IEEE Computer*, *36*(10), 46-52.

Peppard, J., & Breu, K. (2003). Beyond alignment: A coevolutionary view of the information systems strategy process. *Proceedings of the 24th International Conference of Information Systems*, 743-750.

Pettigrew, A. (1995). Examining change in the long-term context of culture and politics. In J. M. Pettings and Associates (Eds.), *Organizational strategy and change* (pp. 269-318). San Francisco: Jossey-Bass.
Pfeffer, J., & Leblebici, H. (1977). Information technology and organizational structure. *Pacific Sociological Review, 20*(2), 241-261.
Porter, M. (1990). *Competitive advantage of nations*, Oxford, UK: Oxford University Press.
Prigogine, I. (1995). An introduction to thermodynamics of irreversible processes. Springfield, IL: Thomas.
Rai, A., & Sambamurthy, V. (2006). Editorial notes–the growth of interest in services management: Opportunities for information systems scholars. *Information Systems Research, 17*(4), 327-331.
Schreyögg, G., & Schmidt, L. (2010). *Organisation and strategy*. Wiesbaden, Germany: Galber Verlag.
Simon, H. A. (1962). The architecture of complexity. *Proceedings of the American Philosophical Society*, *106*, 467-482.
Strauss A., & Corbin, J. (1990). *Basics of qualitative research: Grounded theory, procedures and techniques*. Newbury Wesley, CA: Sage.
Treadwell, J. (Ed.). (2004). Open grid services architecture. *Hewlett Packard*. Retrieved from http://forge.gridforum.org/projects/ogsa-wg
van Maanen, J. (1983). *Qualitative methodology*. Beverly Hills, CA: Sage.
Vidgen, R., & Wang, X. (2006). From business process management to business process ecosystem. *Journal of Information Technology, 21*, 262-271.
Vidgen, R., & Wang, X. (2009). Coevolving systems and the organization of agile software development. *Information Systems Research, 20*(3), 355-376.
Vessey, I., & Ward, K. W. (2013). The dynamics of sustainable IS alignment: The case for IS adaptability. *Journal of the Association for Information Systems*, *14*(6), 283-311.
Walsham, G. (1993). *Interpreting information systems in organizations*. Chichester, England: John Willey & Sons.
Xiao, L., & Greer, D. (2007). Towards agent-oriented model-driven architecture. *European Journal of Information Systems*, *16*(4), 390-406.
Yin, R. (1994). *Case study research: Design and methods* (2nd edn.). Thousand Oaks, CA: Sage.
Zipf, G. K. (1949). *Human behavior and principle of least effort: An introduction to human ecology*. Cambridge, MA: Addison Wesley.

About the Authors

Ramiro MONTEALEGRE is an Associate Professor of MIS at the University of Colorado, Boulder. He received his DBA from Harvard University. His master's degree in computer science is from Carleton University, Canada. He holds a Bachelor of Engineering from the Francisco Marroquín University, Guatemala. His research focuses on the interplay between information technology and organization transformation in highly uncertain environments. He has been involved in studying such projects in the United States, Canada, Spain, Mexico, and the Central and South American regions. His research has been published in *Organization Science, MIS Quarterly*, *Sloan Management Review*, *Thunderbird International Business Review, Journal of Management Information Systems*, *IEEE Transactions on Communications*, *IEEE Transactions on Engineering Management, IEEE Transactions on Systems, Man, and Cybernetics*, *Information & Management*, *Information Technology & People* and other journals. He has received the MCB University Press' "Most Outstanding" Award for his paper published in the *Journal of IT & People*; the "Best Paper" Award of the Organizational Communication and Information Systems Division of the Academy of Management, and "Best Paper" Award of the *IEEE Transaction on Engineering Management* journal.

Dirk S. HOVORKA is an Associate Professor of MIS at the University of Sydney. He holds MSc degrees in Geology and in Interdisciplinary Telecommunications, and received his PhD in MIS from the University of Colorado. His research is centered on the philosophical foundations of IS research with a focus on theory and theory development; design practices, ecosystems, and theory; and on the co-constitutive role of IS in scientific research. He research has been published in the *Journal of the AIS (JAIS)*, *Information Systems Journal*, *European Journal of Information Systems*, *Communication of the AIS*, *Decision Support Systems*, a number of book chapters and, the major IS conferences. Dirk is a co-author on "Secondary Design: A Case of Behavioral Design Research" which received the AIS 2011 Best Paper Award and was *JAIS* Best Paper (2011). His contributions to the IS community include: Guest Senior Editor for editor *JAIS* and *Transactions on Human-Computer Interaction Journal*; Associate Editor of the International Conference on Information Systems, Co-chair "Theories in IS" track at HICSS, Editorial Board member of *JAIS*; Member of IFIP working group 8.2

Matt GERMONPREZ is currently a faculty member at the University of Nebraska at Omaha (UNO). Prior to joining UNO, he was a faculty member at University of Wisconsing-Eau Claire, Case Western Reserve University and a PhD student at the University of Colorado-Boulder. His research focuses on theory and method development and investigation with particular focus on emerging and tailorable technologies. In particular he explores how these new, user-centered technologies are designed and used in practice from the individual to the enterprise level. His work has been funded by the National Science Foundation and accepted in *MIS Quarterly*, *The Journal of the Association for Information Systems*, *Information Systems Journal*, *Information & Organization*, and *The Communications of the Association for Information Systems*.

Appendix: Sources of Data Collected

Table A-1. Sources of Primary Data Collected

Reference	Area / role	Interview Dates
1	Marine Geophysics/User	3/25/08
2	Solar Terrestrial Physics Division/User	3/25/08, 12/22/09
3	Data Administrator	3/21/08, 12/19/09
4	CIRES/ Programmer	3/18/08
5	Geospatial Systems Architect	3/25/08, 12/23/09
6	Director EDS/ DMIT member	3/26/08, 12/30/10, 2/3/10
7	NGDC Director/ DMC member	3/18/08, 12/22/09
8	Programmer	12/22/09
9	Marine Geology and Geophysics/Web Services Architect	12/22/09
10	U.S. Geological Surveys/user	2/9/10
11	Programmer	12/21/09
12	Data Management Consultant	2/11/10
13	National Weather Service/Director of Systems Engineering Center	2/11/10
14	National Weather Service/Data Architect	2/11/10
15	NOAA Data Management Architect/DMIT Chair	2/19/10
16	Technology Planning and Integration Office/Contractor	2/18/10
17	National Marine Fisheries Service/User/ DMIT Member	2/9/10
18	Office of Oceanic and Atmospheric Research/User /DMIT Member	2/9/10

Sources of secondary data collected

- NOAA strategic plan (http://www.ppi.noaa.gov/spo.htm)
- Report to congress on data and information management 2005 (https://www.ngdc.noaa.gov/noaa_pubs/pdf/NOAA_Congress2005.pdf)
- NOAA global Earth observation integrated data environment (GEO-IDE): Concepts of operations, Version 3.3 (https://www.nosc.noaa.gov/dmc/docs/NOAA_GEO-IDE_CONOPS-v3-3.pdf and https://www.nosc.noaa.gov/dmc/swg/wiki/index.php?title=Global_Earth_Observation_Integrated_Data_Environment_CONOPS)
- NOAA global Earth observation integrated data environment implementation plan, Version 1.2
- GEO-IDE project action plan for FY 2010 (https://www.nosc.noaa.gov/dmc/swg/wiki/index.php?title=GEO-IDE_Project_Action_Plan_for_FY_2010)
- NOAA global Earth observation—integrated data environment (GEO-IDE) (https://www.nosc.noaa.gov/dmc/swg/wiki/index.php?title=NOAA_Global_Earth_Observation_--_Integrated_Data_Environment_%28GEO-IDE%29)
- NOAA global earth observation—integrated data environment (GEO-IDE): Guidelines and best practices (https://www.nosc.noaa.gov/dmc/swg/wiki/index.php?title=Main_Page)
- Using the GEO-IDE wiki (https://www.nosc.noaa.gov/dmc/swg/wiki/index.php?title=Using_the_GEO-IDE_wiki)

- UAF technical team (https://www.nosc.noaa.gov/dmc/swg/wiki/index.php?title=UAF_Technical_Team)
- UAF grid test site (https://www.nosc.noaa.gov/dmc/swg/wiki/index.php?title=UAF_Grid_Test_Site)
- Integrated Ocean Observing System (IOOS) (http://ioos.gov)
- NOAA data management integration team (DMIT) workspace (https://www.nosc.noaa.gov/dmc/swg/wiki/index.php?title=NOAA_Data_Management_Integration_Team_%28DMIT%29_Workspace)
- NOAA data management integration team (DMIT) workspace (https://www.nosc.noaa.gov/dmc/swg/wiki/index.php?title=NOAA_Data_Management_Integration_Team_%28DMIT%29_Workspace)
- Open Geospatial Consortium (OGC) website (http://www.opengeospatial.org)
- NOAA ogc interest group website (https://www.nosc.noaa.gov/dmc/swg/wiki/index.php?title=NOAA_OGC_Interest_Group)