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Conceptual modeling for the design of intelligent and emergent information systems

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A B S T R A C T

A key requirement to today's fast changing economic environment is the ability of organizations to adapt dynamically in an effective and efficient manner. Information and Communication Technologies play a crucially important role in addressing such adaptation requirements. The notion of 'intelligent software' has emerged as a means by which enterprises can respond to changes in a reactive manner but also to explore, in a pro-active manner, possibilities for new business models. The development of such software systems demands analysis, design and implementation paradigms that recognize the need for 'co-development' of these systems with enterprise goals, processes and capabilities. The work presented in this paper is motivated by this need and to this end it proposes a paradigm that recognizes co-development as a knowledge-based activity. The proposed solution is based on a multi-perspective modeling approach that involves (i) modeling key aspects of the enterprise, (ii) reasoning about design choices and (iii) supporting strategic decision-making through simulations. The utility of the approach is demonstrated though a case study in the field of marketing for a start-up company.

1. Introduction

The on-going digitization and the ubiquity of software applications meet an ever-increasing pool of users. Their requirements on reliability, usability and affordability are drivers for the development and evolution of software systems that are regarded as the most significant disrupting factor in most industries (Andreessen, 2011) and a key driver in the economic growth of nations (Digital-Europe 2009). One increasingly important consideration is how the design and evolution of the software system can comply with the design and evolution of the enterprise.

The notion of 'intelligence in software' that can adapt itself dynamically to support the ever-changing requirements of markets and enterprises, so that enterprises making use of their Information Systems (IS) to develop new business models even if such business models were not anticipated previously, is a key requirement in today's disruptive environments (ISTAG 2012). Software technologies have been extremely successful at delivering software products of high caliber functionality and at low prices when dealing with systems whose elements are controlled by a single organization (Sommerville et al., 2012). Increasingly however, enterprises (commercial as well as public administrations) collaborate in a variety of ways thus dealing with systems whose elements are operationally and managerially independent. In such cases, the behavior of the components is not known a priori and their requirements are in a state of continuous evolution. Since contemporary applications are dynamic, sooner or later business processes and, thus, their supporting technologies, such as web services, workflow scripts (e.g., BPEL, BPMN), data schemas (e.g., XML, XSL) will need to be changed. In general, this is a problem of both evolution and adaptability of applications.

Fusing traditional business practices with newly developed IS creates new challenges for enterprises to balance between business agility and control. Thus, it is difficult to determine the impact of key decisions, deploy cross-functional initiatives, optimize key resources and funding, and streamline communication between business and IS without a clear strategy that identifies the relation between business change and IS implementation. This has highlighted the need for more powerful concepts, techniques and tools for improving the construction of an IS and for aligning the system to the enterprise business goals and processes.

A key challenge that is addressed by the approach presented in this paper is "How can system developers be guided and supported by appropriate tools to apply *co-evolutionary* design methods where both enterprise capabilities and system functionalities need to evolve to remain relevant?" To address this challenge, it has been argued that a paradigm shift is required, one that considers the development and operation of an IS as a continuous

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knowledge-based activity (Yu, 2009) utilizing conceptual modeling (Guizzardi et al., 2013) as a way to bring together an understanding of complex enterprise phenomena and an attempt to design IS solutions that support agility and dynamic change. This paradigm shift is based on three principles: (a) Systems thinking that considers independent components that form a unified whole (Kawalek, 2004, Wilby et al., 2011); (b) Abstract thinking implying that one moves away from the physical manifestation of processes (Fill, 2014); and (c) Operational thinking that considers the dynamics of a business process and in particular its behavior over time (Sterman, 2000). In terms of processes involved there are essentially two activities: (a) *model building and critiquing* and (b) *simulation and group deliberation*. Models are mainly built by analysts with input from domain experts and are subsequently critiqued and revised by these experts. Analysts also facilitate simulation sessions where model parameters are instantiated by stakeholders. Consensus building stakeholder workshops develop scenarios that facilitate deliberation of alternative future realizations. The new challenges faced by system developers may be summarized as follows.

First, the *design requirements* problem succinctly pointed out in (Brooks, 2010) can now be stated as follows: *What is the emergent behavior and dynamics of the software artifact and its environment in their evolutionary trajectory*? Now users, designers and other stakeholders need to ask: will the system continue to satisfy our emergent goals, and what those goals could be expected to be during the artifact's lifetime; in contrast to the older problem: what are the (fixed) goals of the system and what is it expected to do?

Second, the *specification problem* can be stated as follows: *How can designers anticipate and represent the emergent behaviors of the system and its components and how does the resulting system behavior conform and relate to emerging environments and the notations used to represent and predict it*? Accordingly, designers need to ask how they can represent, communicate and analyze increasingly complex and dynamic systems and their emergent requirements, and how this is possibly conditioned by the nature of presentations brought to bear in the design context in contrast to the older problem: how to faithfully represent the system components, their relationships and behaviors in ways that guarantee that these meet functional and non-functional requirements?

Third, the *predictability problem* of designs can be stated as follows: *How does the artifact and its behavior change the environment as to make our predictions of system behaviors faithful*? In other words, now designers need to attend more closely to the continuous dynamic composition of the system and its environment, and how do they together differ from the environment in separation. Designers need to predict faithfully the impact of the system on the environment, and vice versa. This is a different problem from those faced earlier where the system was assumed to not affect the environment, or the environment the system, with rare exceptions.

These three perspectives are addressed in this paper based on the notion of a multi-perspective approach for knowledge-intensive systems that involve the intertwining of business practices, human activities and IS systems (Fayoumi et al., 2014). This approach is applicable for intelligent emergent software applications where the focus needs to be shifted from engineering of individual systems and components towards the generation, adaptation and maintenance of software-intensive ecosystems consisting of software, hardware, human and organizational agents, business processes and more. We use conceptual modeling for (i) modeling key aspects of the enterprise, (ii) reasoning about design choices and (iii) supporting strategic decision-making through simulations. The resultant benefit from this multi-perspective approach is a systematic way of analyzing and designing robust intelligent IS that can respond in an efficient and effective manner in changes to the business model of an enterprise as a response to either internal or external factors. We demonstrate the approach through a case study focusing on the design of a marketing strategy.

The paper is organized as follows. Section 2 briefly discusses standards and best business practices that are relevant to both business and IS. This section deals with the state-of-the-art of enterprise architecture, enterprise modeling and related modeling standards. Section 3 introduces the way in which our approach is designed to fuse business practices into a formal set of conceptual models to assist with the reasoning, simulation, and development of IS components. Section 4 illustrates the approach with a case study Section 5 concludes the paper with a review of the approach, theoretical and practical insights and finally a reflective discussion on potential future directions for research.

2. Background and related work

2.1. Standards and best practices in business and IT management

As part of the continuous development of business practices, several frameworks, standards, and models have been proposed for improving and benchmarking industrial activities. These were developed with a focus on various business levels (strategic, tactical, and operational). For example, balanced scorecard (BSC) provides an integrated framework in which to implement, control, and measure strategy from the different perspectives of an organization's performance. This assists with high-level managerial decision-making by linking different aspects of the organization together. This framework has been widely adopted by organizations and industry. As presented in Kaplan and Norton (2004), the BSC is used to align four aspects of business strategy—customer, finance, internal business processes, and learning and growth—in order to measure an enterprise's performance. The four aspects of the BSC provide a balance between short-term and long-term objectives, between desired outcomes and the performance drivers of those outcomes, and between soft and hard objective measures. Its main limitation is that it takes time to plan and implement a mature BSC strategy, which prevents organizations from adapting quickly in a dynamic environment.

Total quality management (TQM) is another well-known standard and was one of the earliest to be developed. TQM is based on a strategic approach that focuses on maintaining existing quality standards while making incremental improvements. Some practitioners see TQM as a cultural change initiative, as the focus is on establishing a culture of collaboration among the various functional departments within an organization so as to improve overall levels of quality (Hellsten & Klefsjö, 2000). However, the issues of flexibility, cumulative shared thinking, and enhanced communication were subsequently addressed in the Hoshin Kanri approach of lean strategic development (Jackson, 2006). TQM is often associated with the development, deployment, and maintenance of organizational systems that are required for various business processes (Black & Porter, 1996, Hellsten & Klefsjö, 2000). Other standards, for example, the six sigma approach, have a stronger operational focus. Primarily, six sigma is a problem-solving process that helps to ensure that processes are fully effective. It is an intensive, data-driven approach that focuses on how to eliminate the defects from any process and covers all services, from manufacturing to transactional. The difference between TQM and six sigma is that TQM tries to improve quality by ensuring conformance to internal requirements, whereas six sigma does so by reducing the number of defects within the process. Six sigma relies on intensive quantitative measurement and analysis. Businesses that want to maintain sustainable growth by using the six sigma approach focus on the following four process areas (Hellsten & Klefsjö, 2000).