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Considering context in the design of intelligent systems: Current practices and suggestions for improvement

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ABSTRACT

Ubiquitous sensing allows systems to exploit almost any kind of context, and enables the design of intelligent systems that are aware of their context and adapt their behavior accordingly. As such systems have a number of properties, which distinguish them from traditional systems, their design requires a new approach to requirements engineering and to product development. While existing contributions concentrate on individual aspects in the design process, there is a lack of a holistic perspective on the design of intelligent systems. Considering the entire design process, would allow for the creation of better functioning designs, as has been demonstrated in various fields of system design. Furthermore, little is known about how people design intelligent systems. A deep understanding about design practices is, though, a prerequisite for coming up with systematic improvements. The contribution of this paper is twofold: First, based on interviews, we analyze the design processes undertaken by designers, and present five underlying process archetypes. We focus on how designers identify, select, and consider context across the entire design process. Second, we propose an improved design process for intelligent systems that aims at supporting system designers in their design task in order to serve an organization's, and/or users' needs.

1. Introduction

The design of a system is at the heart of software engineering research. Different approaches to system design have been developed, each with different foci: object-oriented design (Booch, 1982), user-centered design (Norman and Draper, 1986), context-centered design (Beyer and Holtzblatt, 1998), *etc.* Over the last decade, with huge advances in technology, we have observed a trend toward more and more sophisticated systems, termed "intelligent", "context-aware", "adaptive", "situated", *etc.*, hereafter referred to as intelligent systems. Research efforts concerning such systems were originally based on Weiser's vision, where systems are aware of the context that they are used in, and intelligently adapt to this context at runtime (Weiser, 1991). While parts of this vision still remain a vision, a large part of it has already been realized and seamlessly integrated in real-life, everyday systems. Currently realized applications and systems are numerous and include, among others, office automation procedures (*e.g.,* Song et al., 2012), location-based mobile applications (*e.g.,* Gerpott and Berg, 2011), mobile customer relationship management (CRM) systems (*e.g.,* Silberer and Schulz, 2012), and personalized and contextualized advertising systems (*e.g.,* Bauer and Spiekermann, 2011; Zhang and Katona, 2012).

However, little is known about how people actually design such systems (Bauer et al., 2014a, 2014b). Early findings indicate that the design of intelligent systems is complex (Floch et al., 2013) and predominantly technology-driven (Friedewald and Raabe, 2011; Oulasvirta, 2004; Rossi et al., 2005); designers often use the so-called i-methodology (Oudshoorn et al., 2004) and typically come up with *ad-hoc* solutions (Rossi et al., 2005; Serral et al., 2009). In short, system design in the field of intelligent systems tends to be unsystematic. However, the use of unsystematic approaches to system design makes maintenance and later adaptation of systems extremely difficult (Serral et al., 2009). Further, we must also question whether such *ad-hoc* solutions can best address a company's or users' needs. Current research does not go far beyond these initial findings that indicate a mismatch between design practices and needs. However, a deep understanding about these design practices is a prerequisite for being able to evolve and make systematic improvements. Knowledge about the design processes currently undertaken by system designers of intelligent systems is missing.

To systematize the design of intelligent systems, the research community has proposed approaches, frameworks and toolkits. Serral et al. (2009) suggest a model-driven development approach

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for intelligent systems. The MUSIC framework (Floch et al., 2013) provides support by describing typical context and adaptation features relevant for the design of intelligent systems. Further work has proposed a systematic technology selection method for the design of intelligent systems (Razali et al., 2012). Dey et al. (2001) proposed a conceptual framework and a toolkit for supporting the rapid prototyping of intelligent systems. However, the scientific contributions of this work to the field actually address different phases of system design rather than holistically: While some approaches support the ideation phase by proposing typical adaptation features (*e.g.,* Floch et al., 2013), other contributions assume that ideation is already complete and support the requirements determination phase instead (*e.g.,* Sitou and Spanfelner, 2007; van der Zanden, 2008), while further work assumes that requirements concerning context features are already defined and instead support technology selection for implementation (*e.g.,* Razali et al., 2012), *etc*. In other words, existing contributions concentrate on individual aspects in the process of system design. Taking a holistic perspective on the design of intelligent systems (*i.e.,* considering the entire design process) would, however, allow the creation of better functioning designs, as has been demonstrated in various fields of system design (*e.g.,* Charnley et al., 2011; Nilsson et al., 2010).

Against this background, we identify two major research gaps: (i) a deeper understanding about the design processes currently undertaken by system designers of intelligent systems is missing; (ii) there is no systematic design process that supports system designers in their design task in order to serve an organization's, industry's, and/or users' needs.

To address this, we conducted a set of 16 interviews with designers of intelligent systems, hereafter referred to as intelligent systems, in research and in industry in the United States of America, Europe, and Asia. We learned in detail about the procedures that designers followed when designing intelligent systems in their real-world projects. Through our analysis, we identified five different process archetypes, which we will present, compare, and evaluate in this paper.

Further, we propose a novel process for the design of intelligent systems that aims to serve an envisaged purpose, addressing business and user needs. In an evaluation of the suggested process via a further set of 11 interviews with designers of intelligent systems, this process was reported to be valuable for system design; experts expressed that they would use the novel process particularly for achieving incremental innovation. They also said that the different process aspects could be used as a kind of "checklist" to guide the design process. Less experienced designers highly valued the new process because it would help them avoid making the same mistakes as the experienced designers did in their initial projects. Overall, our interviews particularly highlighted that the new process supported the different phases of system design at a coarse (*e.g.,* support in deciding the order of what should be done in the design process) and fine-grained level (*e.g.,* for specifying which context elements should be considered by a system), providing a systematic, yet flexible process that can be applied to a wide variety of design situations.

This paper proceeds as follows: In Section 2 we provide a brief overview of related work on the design of intelligent systems. In Section 3 we describe the qualitative research approach that we employed for eliciting and analyzing the designers' processes. Section 4 presents our findings on the designers' process archetypes and our analysis of these archetypes. In Section 5 we propose an ideal process for the design of intelligent systems, discuss its relation to designers' currently applied processes as presented in the previous section, and demonstrate its utility based on the designers' feedback. Section 6 presents the application of the 'ideal process' in a case study and Section 7 demonstrates how this process may be applied in practice. Section 8 concludes with a summary of the contributions of this work.

2. Background and related work

2.1. Context

The term "context-awareness" in ubiquitous computing was introduced by Schilit et al. (1994). Since then, the context-aware computing community has grown rapidly. With huge advances in technology, we can observe a trend toward increasingly sophisticated systems, termed "intelligent", "context-aware", "adaptive", "situated", *etc*. The joint pivotal element in these systems is known as 'context'.

Although research in context-awareness goes back to the 1990s, there is still a lack of an explicit, single, unified definition of context (Chen and Atwood, 2007). Early attempts to define 'context' in the computer science domain resemble enumerations of examples (*e.g.,* Dey, 1998; Schilit and Theimer, 1994) or synonyms for context (*e.g.,* Brown et al., 1997). More recent concepts are either highly specific to a certain application domain (*e.g.,* Bauer and Spiekermann, 2011) or very generic (*e.g.,* Han et al., 2008). A widely accepted definition was provided by Dey and Abowd (2000), stating that "context is any information that can be used to characterize the situation of an entity". However, characterizing a situation is no easy task: "How are dimensions of context identified, quantified, and interrelated for each situational purpose?" (Bradley and Dunlop, 2005). Given the complexity, variety, and multi-dimensionality of context, system designers have difficulties in identifying and specifying which context is relevant for a system (Choi, 2008). Nevertheless, system designers need to anticipate the relevant combinations and characteristics of context before an intelligent system is implemented in the real world, and decide which context to include in their designs. As context is a crucial element that defines the functionality of an intelligent system and shapes the system's behavior, context selection is a significant task in the design of intelligent systems.

2.2. Processes for system design

In recent years, much effort has been devoted to orient system design toward the situation and needs of a system's potential users (*e.g.,* Iivari and Iivari, 2011; Kohler et al., 2011). In the 1980s, there was increased awareness that the somewhat abstract data that is typically gathered from surveys and focus groups cannot provide the detailed information that designers need about how people carry out their tasks, as Holzblatt (2009) retrospectively points out in her work. This awareness gave rise to the approach known as 'user-centered design' (UCD) (Norman and Draper, 1986), which is intended to support system designers in understanding the context of use from the perspective of future users of a system. Based on UCD, the concept of contextual design (Beyer and Holtzblatt, 1998) provides a set of methods that "tells people what to do at each point so that they can move smoothly through the design process" (Holzblatt, 2009). As ubiquitous, context-aware, and mobile computing requires systems to seamlessly integrate into users' environments (Chen and Atwood, 2007), particular attention has to be paid to the context, in which a system is placed. The framework called 'context-centered design' brings attention to the context in which people will use a system (Chen and Atwood, 2007). Still, this framework does not provide support for designing intelligent systems that automatically adapt their behavior to the situation at run-time.

Irrespective of the design approach selected, the design of a system is always embedded in a more or less structured system design process. Explicit models addressing system evolution date back to the 1950s. The reason these models were introduced was to provide a scheme that allows for managing the design of systems. This scheme