A Research Agenda on Visualizations in Information Systems Engineering

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Abstract: Effectively using visualizations in socio-technical artifacts like information systems and software yields a number of challenges, such as ensuring that they allow for all necessary information to be captured, that visualizations can be efficiently and correctly read, and perhaps most important: that communication is fostered, leading rather to a shared understanding instead of misunderstandings and communication breakdowns. While over the last years many strides have been made to propose visualizations for specific purposes (such as modeling language notations, software interfaces, visual methods, and games), there has been less attention for frameworks and guidelines meant to support the people making such visualizations. When taking a closer look at the deficiencies in research on visualizations in information systems today, it turns out that especially a deeper understanding of the mental processes behind comprehending visualizations and the way humans are cognitively affected by visualizations, is required in order to gain advanced theoretic underpinnings for the creation and use of visualizations in information systems. In this paper we build towards a research agenda on visualization in information systems engineering by identifying a number of relevant requirements for research to address, of fundamental, methodical and tool nature.

1 INTRODUCTION

Research on Information Systems (IS) and the engineering thereof has enveloped a large variety of topics over the past decades. Many fundamental questions on the development and usage of IS together with analysis of data have been addressed. Due to advancements in different domains, diversity of IS usage in various fields and production of widely spread complex data, new problems emerged to represent information and provide interaction with users of IS (Mezhoudi et al., 2015). Advanced visualization techniques are not only required due to technical advancements such as software, devices and infrastructure getting more complex; but also social aspects such as variety of user characteristics, diversifying usages of IS in work processes and everyday life, and change of style in using IS such as multiple working environments and mobile devices (Vanderdonckt, 2005). The availability of vast information makes it hard to navigate through and grasp an understanding of interrelations between data (Rouet et al., 2005).

An example of coherency problems between different visual perspectives is shown in Fig. 1. Here although vast amount of information is visualized in various dashboards, it is hard for the user to establish the interrelations between the analysis screen and navigate through the screens in a structured way. In addition to variety of visualizations in operational phase of IS, usage of diagrammatic visualizations to elicit and communicate requirements, design and develop the system has become a de-facto standard in pre-operational phase (Stahl et al., 2006). Thus, we observe a growing need for systematic and scientific methods to support the design of visualizations in IS in all phases of IS.

To address this issue and identify opportunities for research to contribute to the maturity of visualizations used in IS engineering, in the remainder of this paper we will present a research agenda consist-

[1]Sources: www.cleverq.com, www.inetsoft.com, own illustrations.

Figure 1: Examples of visualizations used in contemporary information systems[1]

ing of a number of requirements for research on visualizations, addressing aspects both on the use and development of IS. Section 2 presents the requirements for developing a research agenda on visualizations in IS. Subsection 2.1 includes the requirements with regard to methodological research foundations, subsection 2.2 covers requirements regarding methods for creating and using visualizations, and lastly subsection 2.3 provides requirements towards research on tooling support. In Section 3, we provide the conclusions and outlook for a research agenda to support the IS field.

2 REQUIREMENTS TOWARDS A RESEARCH AGENDA ON VISUALIZATIONS IN IS

There are several areas that research in IS can (and has been identified to) contribute to. Below is a non-exhaustive list of recently argued important research directions, all covering some aspect of requirements on visualizations. Some of the requirements are also relevant for other fields. They are brought to the foreground here to point out that they lack attention specifically in the IS field.

We have attempted to focus on requirements that address known unknowns and unknown unknowns, which have hitherto received comparatively little attention in conceptual modeling research (Recker, 2015), such as what effective modeling entails, how differences between people affect (interpretation and use of) modeling, and with regard to empirical research with practitioners in the field instead of student experiments. As a result of this effort, we provide a list of requirements identified based on the literature.

While the current list did not result from an (exhaustive) systematic literature review, in our approach we did follow the more common starting point in information systems research of 'snowballing' literature through reference lists (Jalali and Wohlin, 2012) which has been shown to be a good alternative to the use of systematic database searches (Wohlin, 2014), especially for new and emerging topics. Following the guidelines for doing so appropriately (Wohlin, 2014), we focused on finding recent workshop papers proposing research agendas or directions (by searching through titles and abstracts), and from there snowballed to other relevant literature discussing needed research relevant to visualization in information systems engineering. While this position paper is aimed to generate discussion and attention towards visualization issues in IS engineering, we plan in further work to incorporate a systematic literature review to exhaustively categorize current related research agendas and classify ongoing research.

The literature referenced in the requirements point out to either problems or research needs for visualization in IS. In this study, we utilized the problem definitions and needs in the literature to convert them into categorized requirements in the following sections. Thus this paper includes a contemporary and topical list of related work integrated into requirement definitions. There may be other factors necessary to the establishment of well-used visualizations in IS, however, the selected requirements give an overview of issues identified and argued for in recent literature.

The identified requirements are grouped into the three categories "methodological foundations", "methods", and "tool support", relating to respectively the level of scientific contributions that can be expected from their fulfillment, as conceptualizations on the theoretical level, with regard to elaborating methods and procedures, or by fostering the development of supporting artifacts.

2.1 Requirements with regard to methodological research foundations

We see a relatively large number of research questions open about basic conceptualizations of visualizations in IS engineering, which appear to stem from the comparably narrow basis of fundamental research on visualizations in IS so far. The most relevant are listed in the following.

Req 1.1: Cognitive aspects Research on visualizations should incorporate reflections on how the human mind works, and especially how the cognitive apparatus of human beings processes visual impressions (Saffer, 2009; Gulden and Reijers, 2015). As it has been argued that the heart of cognitive science is the way it handles concepts (Fodor, 1998) research in IS stands to benefit from deeper understandings into the fundamental concepts that its actors use every day (cf. (van der Linden and Proper, 2014; van der Linden et al., 2012)). For effective comprehension of these concepts, cognitive science provides the tools to design visualizations that facilitate better engagement of users with IS (Moody,

2009).

Req 1.2: Justified design rationales There is basically no design rationale for visualization choices of notations (Moody, 2009). Proper grounding of the design of visual languages in existing theory, and applying scientific theories of visualization and developments (cf. (Rensink, 2014)) to IS engineering should be aimed at by corresponding research activities. Development of syntactical standards for visualizations can provide the researchers a basis to specify visual languages and a rationale for the selection of choices (Fill, 2009).

Req 1.3: Accommodate mental models The visual notations used in conceptual modeling should accommodate the conceptual distinctions that people make in their own mental models (van der Linden and Proper, 2014). To support this requirement, it is critical that research aids in the design notations that are understandable by end users from their view (Caire et al., 2013).

Req 1.4: Aesthetic relevance Especially with respect to the graphic design of visualizations, scientific research must acknowledge its paradigmatic methodological limitations, and should be open to accept aesthetic judgments besides rationally justified design decisions as one component of creating successful visualizations (Vande Moere and Purchase, 2011). In other words, it must not be denied that beauty plays a significant role in creating and using visualizations (Cairo, 2012), which stands beyond scientific methodical justification.

Req 1.5: Influence of personal factors The requirements for visual notations used in conceptual modeling should reflect those of their users (van der Linden, 2015). Personal factors are found to have important influences on the understandability of models (Reijers and Mendling, 2011), yet are not widespread in current research on the design and use of visual notations and should be methodically incorporated.

Req 1.6: Eliminate communication restrictions Visualizations should be used to eliminate communication problems and noise between domain experts and modelers in knowledge elicitation (Brown et al., 2014). This sociological aspect should as well be represented in the spectrum of research perspectives on visualization in IS engineering, e. g., by reflecting on the discursive interactions among humans who operate with visualizations.

Req 1.7: Cover the entire life-cycle Visualization research should cover the entire life-cycle from gathering information, conceptualizing topologies and structures for visualizations (Cairo, 2012), graphic design for rendering appearances of visualizations, the development of software to display visualizations and provide interactivity, and the practical application of visualizations in various contexts.

Req 1.8: Distinguish different tasks and purposes Different notations and styles for visualizations are used, ranging from very structured formal representations (cf. (Van Zee et al., 2014)) to simple diagrammatic forms and realistic symbolisms. Depending on the modeling task at hand, different ways of visualizing information may be more appropriate (Figl and Recker, 2014). Research should examine dialectal variations of a visual notation in order to properly accommodate the information needs posed by different modeling tasks (van der Linden and Hadar, 2015).

Req 1.9: New fields of applications Research should investigate the use of visualizations in areas that typically lack them. For example, while rule based modeling languages do not generally have a visualization (Wang et al., 2014), often using marked up text like SBVR, they could benefit from visual approaches such as those used for fact-based modeling notations like ORM.

Req 1.10: Criteria for evaluation Criteria for evaluating visualizations in information systems and the research thereof need to be established in the scientific community. Especially, it needs to be discussed whether empiric evaluation by means of questionnaires for users of visualizations is methodologically sufficient.

2.2 Requirements regarding methods for creating and using visualizations

To support the integration of visualizations in IS engineering, scientifically elaborated suggestions for methods and procedures to develop and apply visualizations are required. We regard the following points as centrally relevant and yet missing in IS engineering.

Req 2.1: Terminology for visualization design Research activities should focus on elaborating a domain specific terminology that takes into account the characteristics of spatial relationships and cognitive features of perceiving visualizations (Gulden, 2010). Designers should be able to describe a visualization in a terminology talking about balances, patterns, topologies, granularities, etc. (Cairo, 2012). Such a terminology could base on elaborated sets of terms that have, e. g., been developed in the fields of interaction design (Saffer, 2009; Wong et al., 2011), cognitive sciences (Johnson, 2014) and graphic design.

Req 2.2: Interactive visualizations Research should put into focus the relationships between static diagrams and interactive visualizations, and more effectively harness human creativity and intuition in decision-making and problem solving via interactive visual analytics (Cybulski et al., 2015). While for several types of diagrams, e. g., graph networks or tree structures, a rich body of theoretic knowledge about creating static visual representation exists (Bertin, 1974; Tufte, 1990), the potential of systematically describing interactive capabilities should also be exploited, especially since interaction capabilities are relevant for explorative ex-post analyses (Gulden and Attfield, 2015).

Req 2.3: Enhance static representations of models Methods to express dynamic aspects of concepts should be scientifically developed to enhance static representations used in conceptual models until now (Gulden, 2014; Aysolmaz and Reijers, 2015). Various approaches can be deployed such as the use of animation, narration, and user interaction to reflect the

dynamic nature and enable the users to read the model in a more comprehensible way.

Req 2.4: Use and creation in collaborative settings The importance of the concrete notation in collaborative visualization efforts has been revealed in different domains (cf. (Barjis et al., 2009)), yet recent work on the collaborative specification of (domain-specific) modeling languages has been done, it focused only on syntax and semantics (Izquierdo and Cabot, 2013), neglecting the effect of visual notation choices on its users. More research is needed to support the involvement of people from different backgrounds and capabilities in collaborative modeling efforts (van der Linden and Hoppenbrouwers, 2012).

Req 2.5: Teaching and training Given the difference in reading strategies and efficiency between experienced and less experienced (Petre and Green, 1993), it is important to ensure that users of visual notations are well prepared for their use, which requires more research in understanding the different cognitive and educational processes involved in it, as well as whether to focus on teaching specific visualizations or the different aspects behind them (Recker and Dreiling, 2007).

Req 2.6: Reduce cognitive load Research on visualizations in IS engineering should explicitly state the question how cognitive load imposed by visual interaction with IS can be reduced, e. g., by avoiding navigation steps or lowering the amount of information that has to be memorized by a human user over time instead of being visually accessible (Wong et al., 2011). With less cognitive load allocated to repeated information processing tasks, humans can better concentrate on reacting to new situations and solving non-trivial problems.

2.3 Requirements towards research on tooling support

Some of the research on fundamentals and methods for visualizations in IS engineering base on the assumption that the technical implementation of visualizations can be performed effectively and efficiently. Appropriate tooling support can ensure these assumptions to hold, which the remaining set of research requirements is about.

Req 3.1: Automated design suggestions Research activities should elaborate mechanisms that allow to automatically suggest appropriate visualizations for given classes of data in specific use-cases. This should be made possible by developing generic suggestion mechanisms (Buckl et al., 2010; Gulden, 2015), which are not based on preset templates, but operat with justified design principles derived from advanced theoretic insights (see 2.1). For example, users could be asked to prioritize which pieces of information they find relevant to satisfy information needs. Then, according to design principles for visually expressing hierarchies, contrasts, equality, and relationships, (Spence, 2007; Chen, 2010; Kirk, 2012) the composition of a visualization can be automatically generated as a default suggestion to the user. To provide wider access and standardization, web based visualization services can be developed that can semi-automatically generate visualizations based on user-selected requirements (Fill, 2009).

Req 3.2: Efficient software implementation Research on visualizations should cover reflections on how to efficiently create and maintain software which displays visualizations and provides interactivity (Gulden, 2015). Visualization software of this kind represents a specific class of software component, which allows to adapt techniques for abstracting common features and automating repeated tasks to visualization software development. Especially model-driven software development approaches (Kelly and Tolvanen, 2008) appear to be suitable for this task.

3 CONCLUSION AND OUTLOOK

In this paper we have argued for the need for more research into visualizations in IS engineering. This is due to a lack of research into the way visualizations are involved during the development and use of information systems. We have sketched a preliminary research agenda with requirements based on recently identified forward-looking trends in the IS literature, which especially put cognitive and human-centric aspects into focus.

While we have to stress that the resulting requirements are not an exhaustive view on needed research in the field, they do represent urgent and immediately visible calls for research efforts by those working in the IS field. A careful first look does seem to show many requirements for more topics on methodological research foundations compared to those on methods and tool support. This is in line with the trend in fields such as requirements engineering, where it has been shown that a significant proportion of published research work is design work proposing artifacts to resolve an issue, without necessarily going into the fundamentals of those issues (Wieringa and Heerkens, 2006). Furthermore, the large number of requirements, and thus needed research, on such fundamental topics is in line with Recker's call for more focus on the fringes of conceptual modeling research (particularly relevant to IS), focused on exploring yet unknowns (Recker, 2015).

We hope that by explicating this agenda, we can contribute to the further maturation and development of research on visualizations in information systems. Continuing our own work on the realization of advanced visualization approaches, we hope to also inspire more fellow research colleagues working in the same field.

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