The State of Research on Visualization in Information Systems Engineering

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Abstract. The relevance of information visualization and visual communication is continuously growing on a large socio-economical scale. This implies an increasing variety of applications and research questions related to visualizations that are used as part of information systems, and for the design thereof. Several overview publications have pointed out the relevance of scientific reflection on the use and the effects of visualizations in information systems engineering. This paper aims at taking stock of recent developments in the field and systematizing some recent contributions dealing with cognitive, formal and empirical challenges.

Keywords: information visualization, data visualization, modeling, diagrams, information systems, systems engineering, cognitive factors

1 Visualization in Information Systems Engineering

There is a growing need for systematic and scientific underpinnings of visualizations, as the visualizations incorporated in today's system engineering methods will be implemented in tomorrow's infrastructures and system environments, and thus will shape the way humans interoperate with and benefit from a technologically engineered infrastructure in the future. Information systems engineering is concerned with the processing and usage of information of diverse kinds. To understand and communicate the settings in which systems operate, to interact with them, as well as to conceptualize requirements and design specifications, visualizations have become an important cultural technique for designing and operating systems.

Not despite, but because of its cross-cutting relationships to diverse fields of systems engineering and its fundamental role as an ubiquitous cultural technique, the use of visualizations has not yet systematically been put into the focus of

research activities in the engineering discipline. This seems to be caused by the fact that from the individual perspective of a specialized engineering discipline, the use of visualizations is naturally perceived as merely imported from other disciplines such as graphic design, visual communication, and semiotics. Even in closely related fields of a single discipline such as information systems, there are groups working in, e. g., business process modelling, enterprise modelling, software engineering, and requirements engineering that would share similar, if not outright the same, underlying fundamental challenges, yet do reinvent the wheel by spending time on fundamentals that could be investigated in joint efforts.

The Visualization in Information Systems Engineering Network (VISE-Network) is a recently launched pan-European international collaboration between academic and industrial partners located in Germany, Israel, Luxembourg, the Netherlands, and Turkey. Researchers involved in VISE have all come across different visualization challenges at some point, and realized the use of stronger collaboration to learn from each other's work in dealing with such challenges.

This paper is meant to give a summarizing look on recent advances that VISE members have made in visualization research with respect to information systems engineering. These reflect the research interests of the different members and institutes, as well as already ongoing collaborative efforts for particular visualization challenges. We further hope to stimulate more discourse on these topics, as well as involvement of others interested in visualization research.

2 What have we achieved so far?

The challenges investigated by different VISE members address various concerns, but so far in particular center around those of a cognitive, formal or empiric and methodical nature. The below sections give a brief overview of current ongoing work we address.

2.1 Cognitive viewpoints on visualizations

One of the main purposes of using visualizations in information systems engineering is to communicate knowledge between different stakeholders with conceptual models. The work of the VISE network has shown that the model factors, the characteristics about how the model is structured using its notational elements, have an important effect on the understandability of the models [17]. Even when the model factors are the same, presentation of the models in different modular structures may affect the understandability [16]. Moreover, we have shown that the concrete syntax; the design of symbols, colors and position of nodes; and the design of labels and icons on model elements have an important impact on model comprehension [18, 19, 16]. The guidelines on structuring the specific types of models we have developed became a well-accepted practice [11].

In our studies, the comprehension of models is found to be dependent on personal factors such as background, experience, motivation and learning style

[20, 14]. Improving such personal factors for the specific case where a conceptual model is used even without changing the visual aspects of the conceptual model may help enhance comprehension and communication between stakeholders. Overall, we were able to categorize the factors affecting the comprehension of models based on user characteristics, context and notational properties [24].

We have also focused on utilizing advanced highlighting and animation techniques to enhance the model reading experience [2, 15, 1]. With respect to different modes of perception and their influence on cognitive processing of information, [5] discusses fundamentals on how the use of audio as part of concrete syntax elements of modeling languages can look like.

2.2 Formalizations of visual languages and visual artifacts

Next to ensuring that visualizations are appropriate for their users and their cognitive make-up, ensuring that they can be systematically designed and used is of significant importance. Work of the VISE Network has focused on several aspects here, ranging from introducing meta-models and DSMLs to appropriately use visualizations, to more fundamental work comparing modeling languages using foundational ontologies and investigating the very feasibility itself of formalizing the requirements we have for the design of good visualizations.

The state-of-the-art view on formal visualization modeling assumes that visualizations can sufficiently be described by a one-to-one mapping between conceptual elements and visual representations [8]. To overcome these limitations, [6] suggests a meta-model that introduces additional concepts specific to the domain of visualizations which enrich the semantics of formalized visualization descriptions beyond simple type-to-symbol mappings.

Work on incorporating existing philosophical models into the discourse on visual modeling languages is presented in [13], which examines the Business Process Modeling Notation (BPMN) language on the background of concepts provided in the Bunde Wand Weber (BWW) ontology. Using philosophical work in a responsible way to enrich the discourse in the Information Systems discipline is one of the directions the VISE Network is picking up in ongoing research.

Formalization is used as a way to operationalize aspects of conceptual modeling languages, that is, to ensure their application is systematic and leads to replicable results. The call for formalization has led to efforts to formally verify whether visual notations are cognitively effective or not, by operationalizing (parts of) a widely used theory: the Physics of Notations (PoN) [12]. However, in recent work we examined whether all parts of the PoN theory are equally, or at all, suitable for formalization. We found [23] that not all principles of the PoN can be represented in a formal manner (e. g. using set theory), because they require additional external information which in itself might be difficult to formalize, or in the most difficult cases require direct user involvement.

2.3 Empirical user studies

Empirical work, in particular work involving users of visualization artifacts, is of vital importance to evaluating its benefit in practice. Research done by VISE

members ranges from experiments comparing what kind of diagrams contribute most to comprehension of a domain (e. g., [9]) to studies evaluating the degree to which visualization design involves users in the first place, to the design of platforms fostering collaboration between users of visualizations themselves.

Our network has focused on empirically evaluating model comprehension using different techniques. Retention and transfer tasks have been used heavily to compare the model comprehension under different personal and notational factors [15, 19, 16, 10]. By means of these experiments, we have understood the effect of cognitive viewpoints as discussed in Subsection 2.1 on model comprehension better. The survey studies also support us to understand the viewpoint of model readers [17, 18]. Based on the findings, we deduct that to enhance cognitive aspects in modeling domain, new visualization studies shall consider notational semantics, concrete syntax and personal factors equally to provide better understanding for the users.

While the importance of user involvement in the design and development of visual artifacts is widely accepted, many efforts do not manage to reach significant levels of user involvement. In a recent work [22, 21] we explored to what degree applications of the PoN involved users. We found that a significant amount of applications did not involve users at all, whether for the critical analysis of existing visual notations, or the design and implementation of new ones. This means that little requirements elicitation for the visual notation is actually done with the very people using it.

In an ongoing project we are designing a platform, or perhaps, *marketplace*, for the collaborative design and evaluation of visual elements. Initially this is targeted at elements of visual notations for modeling languages, but it can be used for other visualization efforts as well. This could lead to a kind of 'certification' for visual elements: that particular core elements are known to be interpreted correctly and efficiently by users, in which contexts it is so, and for what purposes it is already used.

2.4 Applications of visualizations

Besides knowing how to create good visualizations, it is important to know how to put them to good use. This ranges from being able to select the appropriate kind of visualization and its parameters, to setting up interaction strategies. VISE members are working on topics like the animation of process models and other kinds of annotations, as well as on methods for applying visual models in software development processes.

We have used highlighting of process model constructs to focus the readers to the relevant parts of the model [15]. To include the readers better in the process of reading, animation support based on different scenarios, textual and audio annotations, and active involvement of users via controls are essential [2]. Currently we are developing process model animation techniques to guide the focus of the users as they read the models and enhance comprehension [1].

Utilizing visual models as construction tools in model-driven software development processes requires to embed them into a tool chain where their formal

content is further analyzed and transformed by code generation and interpretation techniques. While traditional approaches mainly focus on general purpose modeling languages with few semantic expressiveness, [4, 3] put semantically rich domain-specific visual enterprise modeling languages into focus for this.

An approach for automatically suggesting visualizations for data analyses in specific domains is introduced in [7]. It is based on domain-specific semantic characteristics of the underlying data, which allows to narrow down the range of useful analytic views compared to merely syntactic approaches.

3 Future outlook

In this paper we have given an overview of recent work by VISE members on different visualization challenges in information systems engineering, from dealing with the cognitive point of view to formalization and empirical work. We hope to stimulate more researchers interested in visualization to collaborate on these and other challenges and exchange their insights on research strategies to best deal with these and other emerging challenges in the field of visualization in Information Systems.

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