Toward Advanced Visualization Techniques for Conceptual Modeling

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Abstract. Conceptual models and their visualizations play an important role in the in the Information Systems (IS) field. Their track record, however, is mixed. While their benefits are clearly perceived, practitioners also struggle with their use. This paper picks up on a potential factor that limits the effectiveness of conceptual models, namely the poor design rationale behind their visual appearance. We argue for the benefits of a holistic view on the visual side of a conceptual modeling technique, which should draw from both perceptual and cognitive theories to improve the representation of objects. We present concrete activities and outline their fundamentals in the form of a research agenda.

Keywords: Visualization, Analysis, Modeling, Cognitive Efficiency, Human-Computer-Interaction

1 Introduction

The IS discipline is concerned with the processing and usage of information within organizational contexts. To understand and communicate the setting that information systems need to operate in, as well as to specify the requirements such systems need to adhere to, *visual conceptual models* have become an important aid. Visual conceptual models cover a wide variety of representations, such as class diagrams, business process models, use case models, etc. They are commonly used to reflect a designer's understanding of a system as it is working or as it is intended to be working. A conceptual model can be used to validate such an understanding with business professionals, or to guide developers to actually build a system, among other purposes. The effort that is spent on creating a conceptual model often pays off in terms of the efficiency or effectiveness of the project it is used in [14, 24].

Conceptual models are often displayed in visual form, e. g., as diagrams, to represent abstract data. The idea behind this is that such a *visual* approach stimulates natural characteristics of visual processing in human cognition. Despite the obvious relevance of the visual side of a conceptual model, existing research

on this aspect of conceptual models is fairly thin. The exact way how to visualize information is still widely regarded as a cosmetic concern, secondary to the *meaning* of the information captured. Consider, for example, the appearance of a modeling language like YAWL: The visual appearance of the modeling constructs has obviously been a much lesser concern than the specification of their formal semantics [4]. While recent research has certainly picked up on visual aspects of a conceptual model, e. g. in [15, 9, 5], the emphasis is on the effective *use* of the visual aspects of a modeling technique – not the proper *design* or *redesign* of the technique itself.

In this paper, we argue that the visualization rationale behind a conceptual modeling technique must be treated as a primary concern by the IS field. Specifically, we believe that there is a need for *theoretic strengthening*, which should rest on a deeper understanding of what conceptual models aim to capture: the complex socio-technical interplay among humans and software systems.

Our contribution is a research agenda which is founded on the insight that the capabilities of the human brain are essential ingredients for visual design. The research that we outline is meant to enhance the use of conceptual models toward a higher level of effectiveness. Despite their noted success, it must be acknowledged that conceptual models still pose difficulties with users, specifically non-experts [1, 3, 19]. By considering both the conceptual and perceptual qualities of IS artifacts in an integrated way, a conceptual model potentially becomes a more readily usable asset. A key element to achieve this is to assign a real-world semantics to its elements, which was already identified as a research challenge in [24] but not picked up on so far.

This position paper is structured as follows. In Section 2, theories and related work will be discussed that are relevant for our research agenda. Proposals for research directions are then presented in Section 3. We will conclude this paper with a summary and outlook in Section 4.

2 A theoretical view on information visualization

2.1 Demand for theoretical underpinnings of information visualization in IS

While visualization techniques are to some extent studied by IS scholars, we consider it remarkable that the techniques for conceptual modeling have barely evolved from a visual perspective. The most dominant techniques for business process modeling, for example, are still highly similar to the archetypical "process flow chart" proposed in the 1920s [7]. Specifically, a process model – whether expressed as EPC, BPMN model or UML Activity Diagram – is still shown as a static diagram in which different types of symbols are connected by arrows. Considering advances that have been made in fields such as computer animation and information visualization in recent years, it seems reasonable to expect that untapped sources exist for better depictions of conceptual models. In this section, we will review a number of disciplines and their corresponding theories for inspiration.

Graphic Design The field of Graphic Design research has developed and explicated design recommendations and quality criteria for visualizations in diverse areas of practical applications [18]. The focus is primarily on aesthetics, with questions about the cognitive impact of visual expressions in the center of the discipline, and reasoning about transporting conceptual meaning and understanding towards its periphery. Graphic Design offers a stable core of knowledge about the effectiveness of different visualization modes. The terminological apparatus of Graphic Design research for reflecting about visualizations goes far beyond the simplified notion of hierarchically composed, atomistic graphical shapes as being common in IS today. It thus can be expected that incorporating parts of the stable core knowledge achieved in Graphic Design will provide a relevant theoretic advance for IS research on conceptual model visualization.

Interaction Design Research activities in Interaction Design especially care about how environments for presenting information should be shaped in order to allow humans to accurately make sense out of information [20]. The core idea is that suitable ecological settings influence the way information is perceived and processed [23]. Interaction Design does not embrace visualization techniques as its core concern, but rather cares for analyzing information needs and reasonably arranging visualization techniques and other means of human-to-software communication to fulfil them efficiently. In this sense, it lies in the very center of Interaction Design's interests to theorize about relationships between perceiving and understanding, which is one key element for an advanced handling of visualizations which is yet missing in IS research on visualization.

Cognitive Science Cognitive Sciences operate in the force field between reasoning about thinking and understanding, and examining characteristics of the mind, down to the physical functioning of the human brain. While in Graphic Design phenomena such as gestalt perception and pre-conceptual categorizations are taken as-is and are systematized specifically for the purpose of providing design recommendations for visualizations, the focus in Cognitive Science is much wider and incorporates research about all cognitive phenomena and mental capabilities [2]. Besides language use, memorizing, and reasoning, e. g., this also covers visual processing of the human mind and the relationship between seeing and understanding. When it comes to finding means for assessing the efficiency of specific modes of visualizations for conceptual models in IS, Cognitive Sciences are likely to provide appropriate fundamentals.

Philosophy of Mind The philosophical direction of Embodied Cognition offers an explanation model for human thinking which derives capabilities, such as speaking languages or understanding abstract concepts, from basic experiences humans make as bodily beings in a physical world [12]. According to this approach, humans repeatedly perceive patterns (such as "things fall down when they don't have a surface to rest on", or "two objects cannot be simultaneously in the same place"), which, after repeated steps of metaphorical abstractions, finally let higher-level cognitive capabilities emerge. Given the elaborations of this idea available from philosophical works, a translation of key concepts for ap-

plication in IS can be expected to contribute to a rich terminological apparatus for reflection on model visualization.

2.2 Related work

As stated in the introduction, most work that considers visual aspects of conceptual models focuses on the best possible use of the visual elements of existing techniques, as in [15, 9, 5]. In these types of work, the modeling technique itself is not put into question. Only a few attempts to systematically introduce research questions around model visualizations exist in IS and its neighboring discipline computer science. [22] attempts to develop a measure for the economic value of visualization based on effectiveness and efficiency. By focussing only on cost aspects, however, a qualitative evaluation of information visualization is not considered at all. As [17] remarks, the differences between textual languages and visual representations are so diverse "that fundamentally different principles are required for evaluating and designing visual languages". The proposed solution, however, remains limited by typical paradigmatic presuppositions that are common in the way visualization is treated in IS research today (see 2.3).

Other contributions in the literature, which put data or information visualization into focus, e. g. [21, 13, 25], operate mainly on a visual design level and do not embed their examinations into the wider focus of reasoning about developing modeling techniques and improved information systems.

2.3 Shortcomings of current approaches

The current state of theoretic reflection about model visualization is characterized by a set of paradigmatic limitations, which narrow down existing approaches to operate with restricted notions of visualizations. Some presuppositions by which current research is constricted become visible in Moody's attempt [17] to provide a theory on the "physics" of notation. While the approach is thoroughly motivated by the identification of severe weaknesses in current reflections on visualizations, the examination carried out contains statements such as "there must be a one-to-one correspondence between symbols and their referent concepts" (cited from [8]). This explicitly excludes a notion of patterns as carriers of meaning in visualizations, although there is strong evidence that exactly the cognitive capabilities of processing of patterns rather than linear language is one key element of understanding visual perception.

Additionally, [17] claims that it "says nothing about [...] semantic issues". This expresses an aim for introducing a methodological simplification in order to make the examination better handleable. However, as argued above, there are good reasons to believe that fruitful answers to questions about predicting and measuring the cognitive effectiveness and efficiency of visualizations can only be given when a joint theoretic view on conceptual thinking and perceptual processes is taken in. Indeed, the methodological separation of conceptualization and representation might be the *very* reason why visualization research in IS currently seems to be stuck in a crisis.

3 Research direction

3.1 Seeing is thinking, and vice versa – overcome the methodical reductionism that divides conceptualization and perception

It is a widespread belief that the use of visualization for communication increases the efficiency and accuracy of communication, because the cognitive apparatus of humans handles visual impressions differently from spoken or written language. When seeing, humans can simultaneously grasp an unvisualizationderstanding on multiple levels of granularity. Complex relationships can easily be understood by being affected by patterns, and understanding visual impressions can happen in parallel. This is only possible because in our minds the *conceptual qualities* transported by a visualization, i. e., knowledge expressed by it, and the *perceptual qualities*, which are the visual impressions that shape the way our minds handles the perceived impressions, are intricately intertwined [11, 16].

The very question of how to make "good" visualizations implies that conceptual thinking and visual thinking must be brought together. Separating conceptualization and perception would lead, in our view, into the wrong methodological direction. By this separation, any attempt to gain a prescriptive theoretic approach that allows to consciously judge why some visualizations will lead to a more efficient and accurate understanding than others is jeopardized from the very beginning, because the "understanding" side is excluded beforehand.

Rather than trying to approach the research questions by seemingly reducing the complexity, but, in fact, preventing an appropriate argumentation architecture for answering the questions, a theory seems required that offers a combined view on conceptual semantics and perceptual qualities. The road toward an elaboration of such an approach is sketched in the remaining part of this paper.

3.2 Developing an advanced theory for information visualization

We suggest to follow some coarse-grained steps for performing research in the direction that we outlined.

In an initial phase, the existing body of knowledge from disciplines such as graphic design, interaction design, cognitive sciences, gestalt psychology, and philosophy of mind should be examined to find stable theoretic knowledge in which conceptual elements and visual design rationales are systematically combined. Prospectively, it will be sufficient to concentrate on core elements of the respective disciplines which are no longer undergoing intra-disciplinary discussions.

Based on conceptualizations from these research areas, a linkage to IS can be established by applying its methodical means, such as conceptual modeling, meta-modeling, knowledge representation and transformation techniques, to "translate" the imported knowledge from other disciplines into languages of IS. This procedure resembles one of the very core competencies and purposes of IS, namely the terminological reconstruction of domains of discourse to (semi-)formal languages [6] for the further design and development of information

systems. The notable difference in this case is the terminological reconstruction performed on the methodological level to establish scientific means for constructing IS methods, instead of performing it on the methodical level, where external domains of discourse are investigated.

Once conceptualizations in the languages of IS are made explicit, software can be described using the imported concepts. For research purposes, tool support for software-based visualization methods in IS can be provided. The capabilities of these solutions cannot yet be described more precisely, because they will become characterizable only as a result of the examinations on imported knowledge from other disciplines.

With the existence of prototypical methods with implemented tooling support, visualization approaches will become eligible for systematic evaluation through established design science criteria [10]. Evaluation can either be performed qualitatively, i. e., by analyzing and comparing visualization approaches with the terminological equipment developed through the reconstruction of imported theories, or quantitatively, i. e., by applying empirical experiments and surveys.

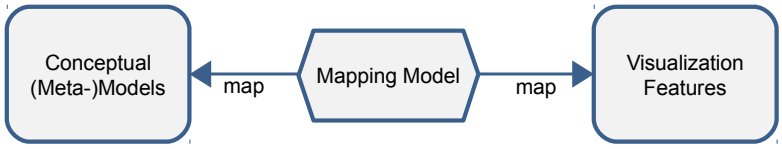
3.3 Theory architecture

Our proposal extends the existing and in our view oversimplified architecture of existing visualization approaches for conceptual models, as it is displayed in Fig. 1 (a). The traditional view assumes that visualizations can sufficiently be described by one-to-one mappings between conceptual elements and visual representations. The specification of visualizations is performed on the level of meta-models, where types of model elements and types of visual elements are related to each other.

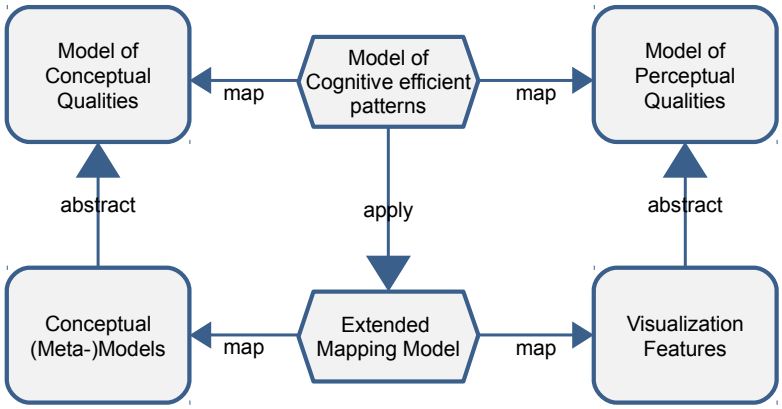
The extensions of the theory architecture that our proposed research program implies incorporate an *additional* level of reflection on the meta^2 level. Fig. 1 (b) illustrates this by repeating the original mapping structure in its lower part, and adding the element "Model of Conceptual Qualities" which represents terminology to describe characteristics of meta-concepts, the element "Model of Perceptual Qualities" which represents imported knowledge about visualizations with regard to their cognitive impact and features that influence their understanding, and the element "Model of cognitive efficient patterns" which stands for IS-specific insights about combing the other two. It should be noted that at the current stage of formulating the demands for a research program on conceptual model visualization, the introduced meta elements merely act as placeholders for research results yet to be achieved. Possible manifestations of these elements, and their representations in formal document artifacts, still remain to be elaborated.

4 Conclusion

In this work, we have signalled a fundamentally flawed view on the role of visualization aspects of conceptual models. Our argument, inspired by a range of



(a)



(b)

Fig. 1: Traditional notion of a visualization specification (a), and the suggested extensions (b)

theories, is that a separation of conceptual thinking and perceptual processes is a dead end. Considering the importance of conceptual modeling for the IS field, it seems appropriate for researchers in this discipline to take on the challenge and embrace a wider perspective on visualization research than characteristic for the state of the art. It is our hope that the research agenda we provided may serve as an inspiration for this endeavor.

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