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Improving cognitive effectiveness of business process diagrams with opacity-driven graphical highlights

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ABSTRACT

In order to facilitate the communication between the stakeholders, business process diagrams must be easy to understand. This is challenging to achieve, since they can become large and complex. In our previous work, we proposed Opacity-Driven Graphical Highlights, a novel approach for increasing the cognitive effectiveness of business process diagrams by changing the opacity of graphical elements and provided a prototype implementation of the approach. The goal of this study was to empirically validate if our proposed approach positively impacts cognitive effectiveness of business process diagrams and if the users will find the prototype implementation useful. To this end an experimental research was conducted where speed, ease and accuracy of answering questions were observed along with the perceived usefulness of the prototype. Participants that used Opacity-Driven Graphical Highlights significantly outperformed those that used the conventional approach. We can conclude that using Opacity-Driven Graphical Highlights increases the cognitive effectiveness of business process diagrams, while the corresponding prototype is perceived as being useful.

1. Introduction

Business processes are core asset of organizations, which aim to facilitate the exchange of business-related operational and strategic information [1], necessary for performing effective decision-making [2]. Business processes can be represented in a form of business process models that capture both how the business works and how the value is created for various stakeholders [3]. It is a common practice to represent a business process model visually - in form of a business process diagram (hereinafter referred to as BPD) [1].

BPDs are commonly modeled in graph-oriented business process languages (i.e. visual notations) [4], which form an integral part of the language of software engineering and tend to be effective because they tap into the capabilities of the powerful and highly parallel human visual system. Notations may be more or less effective, where the cognitive effectiveness of the corresponding BPDs-based communication is mainly influenced by how the modeler and the reader understand the same BPD [5]. Regardless of the effectiveness of notations, BPDs can easily become large and difficult to understand [6] also due to the complexity of the nature of the problem, which needs to be solved [7].

Many principles were suggested in order to improve cognitive effectiveness, e.g. dual coding, visual expressiveness and complexity management [5]. Among those, some might be part of notations, e.g. elements, which enable a hierarchical decomposition of a BPD, or elements, which abstract parts of a BPD. Others might leverage the flexibility of the elements' non-standardized visual variables for enriching their information (e.g. associating a specific color with an organization's role). The application of these principles have demonstrated several benefits, e.g. improving comprehension of BPDs [8,9]. However, since these approaches intervene with the notation or BPD definition, they require that information of applied principle is stored in BPD's model or meta-model. While this is not an issue in case when the applied principle is part of a standard, it becomes critical when it is out of the scope of a standard (e.g. interoperability and compatibility issues between tools [9]). Thus, our motivation was to propose a novel approach for improving cognitive effectiveness of BPDs, which is notation and BPD independent and leverages the principle of visual expressiveness in order to make the BPD appear less complex [10]. This was achieved by introducing Opacity-Driven Graphical Highlights, which is based on manipulating the opacity of BPD's graphical elements. We also implemented a prototype software solution, which demonstrates the proposed approach.

In this paper, we present the results of the empirical study, conducted to investigate if the introduction of Opacity-Driven Graphical Highlights improves the cognitive effectiveness of BPDs (RQ_1) and if users will find the corresponding prototype software solution useful (RQ_2). These objectives were achieved by organizing our research and this paper as follows. The second section focuses on research background, namely BPDs and notations, complexity of BPDs and cognitive

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effectiveness of BPDs. The third section provides the related work, with the focus on approaches that tend to improve cognitive effectiveness of BPDs. The fourth section overviews our previous work, i.e. theoretical foundations, proposed set of Opacity-Driven Graphical Highlights and the implementation of the prototype. The fifth section presents the details of the empirical research, whereas the sixth section provides the analysis and results of the gathered data. The last section reviews the limitations along with the implications of this research and provides an overview of the future work.

2. Research background

2.1. Business process diagrams and notations

Business process modeling is the activity of graphically documenting and representing business processes [11], which is at the heart of modern organizations. Large organizations manage thousands of BPDs in their process repositories, since they form a knowledge base that enables a competitive advantage [12,13]. BPDs enable business users to understand the process and share such an understanding with the rest of the stakeholders [1] as well as to find possible points of improvements in the process [11]. Furthermore, BPDs are considered as one of the mechanisms to guide decision-making in the business processes [14]. This is reasonable, since BPDs can convey information clearer and more precise than ordinary language. Besides, due to the picture superiority effect, information represented visually is more likely to be remembered [5].

BPDs are created by using process modeling notations, which generally provide means to graphically represent activities, events, resources, roles, actors, functions, organization and hierarchy with the aim to compose a business process and its surrounding area [11]. To achieve this, process modeling notations primarily consist of graphical symbols, definitions of the meaning of each symbol and a set of compositional rules [5].

There are many notations that enable business process modeling. However, to reduce the risk of misunderstanding the conveyed information, it is preferred to model the BPDs using a notation, understood by all stakeholders [1]. Among those, BPMN is considered to be the de facto standard in business process modeling [15,16] and is one of the most widely used process modeling notations [11].

2.2. Complexity of business process diagrams

Since BPDs can grow to be large and difficult to understand [6], they can become a barrier rather than an aid in the communication. This is due to the fact that the amount of information, which can be effectively conveyed by BPD, is limited by human perceptual and cognitive abilities. In this light, perceptual limits address the situation, where the ability to visually recognize the distinction between diagram elements decreases with their number and proximity. Also, the number of elements that are understood at a time is limited by working memory capacity, which is considered to be a cognitive limitation [6,17].

BPDs can become complex [7], which can negatively affect their correctness, maintainability and understandability [18]. Moreover, if a BPD is complex, it can become harder to determine if it properly represents the business process and can potentially hinder the communication with stakeholders [19] [20]. Evaluation of the complexity of BPDs can be achieved by using measurements to assess whether a BPD is easy or difficult to understand. Such measurements are commonly referred to as complexity metrics [21].

2.3. Cognitive effectiveness of business process diagrams

As already stated, BPDs have to be effective in making the human communication and problem solving easier. This can be achieved by reducing the cognitive load, which represents the total amount of mental effort being used in the working memory at a point in time [22]. Therefore, BPDs have to be optimized for processing by the human mind, since the visual representation of BPDs offers little or no value for communication with computers [23]. As such, Cognitive Load Theory provides instructions on how to present information in a way that reduces the cognitive load and optimizes human understanding. Cognitive Load Theory further differentiates between intrinsic cognitive load, which derives from the complexity of the domain and extraneous cognitive load, which is dependent on how the information is presented [22].

In such manner, cognitive effectiveness of BPDs was summarized by Moody et al. as "*the speed, ease and accuracy with which a representation can be processed by the human mind*" [24]. However, cognitive effectiveness is not an intrinsic property of the BPDs. Rather, it is something that needs to be designed into them. Thus, not all BPDs are equally effective in making the human communication easier [24].

Moody [17] proposed a set of evidence-based principles for producing cognitively effective BPDs. Among those, emphasis has been recognized as a concept that dramatically improves understandability and problem-solving performance by highlighting BPD elements with higher relative importance, while the less important ones should be lowlighted.

3. Related work

There are many recommendations for improving the cognitive effectiveness of BPDs. In this light, Moody [17] focused on complexity management and suggested that large BPDs should be divided into smaller, cognitively manageable parts, an approach, which is also known as decomposition. The effectiveness of decomposition was empirically validated and the results showed that by reducing a model to chunks of manageable size, complexity was reduced and understanding improved [25]. In addition, Gruhn et al. [26] proposed the improvement of the BPDs' understandability by introducing three groups of workflow-related patterns, namely: (1) finding and removing unnecessary OR gateways, (2) empty sequence flows and (3) reducing the number of model elements.

The aforementioned recommendations can be implemented on different technical levels. On the level of the notation, several mechanisms, which address cognitive effectiveness by coping with complexity, are already implemented within notations, e.g. link events for modularization and sub-processes for hierarchy in BPMN [27,28]. To this end, studies that introduced additional elements had to intervene with the corresponding notation. For example, in order to simplify existing temporal BPMN constructs, Gagne & Trudel introduced Time-BPMN, an extension to BPMN [29].

On the level of BPDs' definitions, the mechanisms, which address cognitive effectiveness, tap into the flexible properties of the graphical elements. Commonly, these properties have to be written in the definition of BPD. In this manner, La Rosa et al. [19] identified eight notation-independent patterns, which generalize various approaches to change the visual representation of BPDs in order to reduce their complexity. Among them, Graphical Highlight pattern is most relevant for our study, since it can reduce the cognitive overhead. It refers to the features that change the visual aspect of elements, e.g. shape, line thickness and background color, which reduce the cognitive overhead of linking syntactic elements with their corresponding semantics. Besides, Kummer et al. [30] have also recognized color highlighting as the most widely used mechanism for reducing cognitive load. Furthermore, Reijers et al. [8] proposed the use of colors to highlight matching operator transitions (i.e. gateways). The authors formalized the concept for syntax highlighting in workflow nets and implemented it within a Petri net modeling tool. Afterwards, an experimental study was conducted, which explored the effects of highlighting on comprehension performance. The results showed that in the case of non-expert (novice) users, the highlighting significantly increased their performance when

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