Improving Comprehension of Process Diagrams with Graphical Highlights

Gregor Jošt

The Faculty of Electrical Engineering and Computer Science at the University of Maribor, 2000 Maribor, Slovenia
gregor.jost@um.si
https://feri.um.si/en/about-us/

Business processes are core assets of organizations, and they reflect what companies do when they deliver services or products to customers. As such, an organization can outperform its competitors if it has more effective processes and executes them more efficiently [5, 10]. This is reasonable, since process-oriented structures help organizations to adapt to the increasingly changing environment [20].

Business processes can be represented in the form of *business process models*, which capture both how the business works, and how the value is created for various stakeholders [20]. In this regard, business process models aid in the communication between the stakeholders, thus, they must be easy to understand [9]. While business process models can be represented by means of textual description, it is a common practice to depict them graphically [3] with *business process diagrams* [5].

There are many *visual languages* for representing business processes diagrammatically. However, choosing the most appropriate visual language for diagrammatic modeling is not a guarantee for a more effective communication between the stakeholders. The effectiveness of such communication is influenced mainly by how the intended message (i.e., how the modeler understands a diagram) matches the received message (i.e., how the reader understands the same diagram) [15]. This can become challenging to achieve, as business process diagrams can easily become large and difficult to understand [19]. This is often due to the complexity of the nature of the problem, which is reflected directly in the business process diagrams. On the other hand, they can also become unnecessarily complex, since one behavior can be modeled in different ways [11]. Indeed, one of the most common mistakes when modeling diagrams is to display too much information on a single diagram, which increases the diagram's complexity needlessly [14]. Incorrect understanding of business process diagrams can cause a variety of issues [1], e.g., inadequate implementation of the corresponding supporting systems and other design flaws [11]. Complex business process diagrams can also become a barrier rather than an aid to communication with stakeholders [14], and can make it harder to determine if they capture the business practices correctly [18]. Considering this, we can conclude that the complexity of a diagram directly affects its comprehensibility [11, 13] (sometimes used as a synonym for understandability [4]), since there are limits in human cognitive capabilities to make sense of complex diagrams [19].

In this light, cognitive effectiveness of diagrams was defined as the speed, ease, and accuracy with which a model representation can be processed by the human mind [14]. However, cognitive effectiveness is not an inherent property of diagrams, but it must be designed into them. To this end, nine principles for creating cognitively effective diagrams were proposed, namely [14]:

1. Discriminability,
2. Manageable complexity,
3. Emphasis,
4. Cognitive integration,
5. Perceptual directness,
6. Structure,
7. Identification,
8. Visual expressiveness, and
9. Graphic simplicity.

Some of these principles are already integrated in the diagramming notations, e.g., Business Process Model and Notation (BPMN) has built-in mechanisms for managing complexity in the form of Link Events for achieving modularization and Sub-Processes for hierarchic structuring [8]. Regardless of these built-in mechanisms, managing complex business process diagrams is a task that is still fraught with challenges [18]. This might also be because, according to Moody [14], the design of diagramming notations is mostly unscientific and based on personal taste or intuition. Indeed, some of the most predominant diagramming notations that enable modeling of business process diagrams are perceived as being complex and not easy to learn, even for business analysts [6]. Similarly, modelers are typically not instructed on how to create cognitively effective diagrams, hence, they rely on their intuition and experience. As such, the resulting diagrams might distort the information, or even convey unintentional messages [14]. Hence, it is reasonable that there is a considerable body of literature regarding the cognitive effectiveness of business process diagrams. These studies commonly apply the aforementioned principles for creating cognitively effective diagrams by leveraging the extensibility of the elements' non-standardized visual variables for displaying different kinds of information. This is also known as *secondary notation* [15], which can improve the comprehension of diagrams (e.g., associating a specific color with an organization's role [17]). Other studies propose extensions of the existing diagramming notations [21], which do not violate the specification, but they change the corresponding metamodel (e.g., simplifying temporal constructs in order to increase readability [7]).

To summarize the above, the main purpose of business process diagrams is to facilitate the communication between the process-related stakeholders, which directly affects the decision-making. For this reason, they must be easy to understand. However, this is often challenging to achieve, since business process diagrams can become large and complex. In this light, the low level of modeling competence in a casual modeler has been recognized as one of the main causes that process diagrams lack in quality [12]. The common modeling mistakes can make diagrams a barrier instead of an aid to communication [14], and poorly

designed diagrams may be even less effective than text [16]. To this end, many frameworks, principles and guidelines for modeling were proposed. While they commonly lack a sound research foundation, or are too abstract [12], several attempts were made to provide empirically-based and operational guidance for both designers and users of diagrams, e.g.: [14, 12, 2]. However, the majority of these approaches intervene in the diagramming notations' specifications or the business process diagrams' definition. As such, they require that the information of applied principle is stored either in the process diagram's model or the diagramming notation's metamodel. This can cause several issues, e.g., interoperability and compatibility between the diagrammatic tools is hindered [17]. Furthermore, overuse of specific approaches (e.g., Graphical Highlight pattern [18]) may lead to potentially unreadable process diagrams [18].

Based on these challenges, the goal of this doctoral thesis was to propose and investigate a non-intrusive approach that makes business process diagrams appear less complex, without changing the corresponding diagrammatic notation or the business process diagrams themselves. This was done by manipulating the opacity of graphical elements in order to emphasize the important parts of a business process diagram by lowlighting the irrelevant ones. The proposed solution, named *Emphasis, implemented with opacity-based Graphical Highlight pattern*, abbreviated as simply *Graphical highlights*, introduces six Structural and seven Behavioral Graphical highlights.

Graphical highlights were firstly applied to a sample business process diagram, modeled in Business Process Model and Notation (BPMN). The analysis addressed the real-world procedure, and based on the survey of the process, we applied one representative of Structural and one representative of Behavioral Graphical highlight, respectively, to the conventional process diagram. Afterwards, the complexity analysis of all three process diagrams was performed. Based on the results of the analysis, we can conclude that the application of either Structural or Behavioral Graphical highlights decreased the complexity of the highlighted part of the process diagram in almost all of the observed measures. In several cases this meant that understandability of the process diagram increased.

Afterwards, a Web application prototype was implemented, which supports the proposed set of Graphical highlights. The prototype can render the business process diagrams and provide the support for both categories of the aforementioned Graphical highlights. The back end of the prototype was implemented in PHP: Hypertext Preprocessor programming language, while the front end is served using the AngularJS, a JavaScript open-source web application framework, and Bootstrap, a framework for developing responsive and mobile-friendly Graphical User Interfaces (GUIs).

Furthermore, we empirically validated whether Graphical highlights positively impact cognitive effectiveness of business process diagrams, and if the users will find the prototype implementation useful. To this end, an experimental research, which included 85 participants, was conducted. The participants were randomly assigned in either the treatment group (Graphical highlights di-

agram representation approach), or the control group (conventional diagram representation approach). In accordance with the definition of cognitive effectiveness, speed, ease, and accuracy of answering 26 comprehension questions were observed, along with the perceived usefulness of the prototype. The results of the analysis demonstrated that participants who used Graphical highlights significantly outperformed those that used the conventional approach in all experiment's observations.

We can conclude that using Graphical highlights increases the cognitive effectiveness of business process diagrams, while the corresponding prototype implementation is perceived as being useful by the experiment's participants. The results supplement the related work, which demonstrated that the color-based Graphical Highlight pattern is perceived as useful and increases the ease of use. However, conversely from the related work, Graphical highlights do not interfere with either the diagramming notations or with the process diagrams. Since process diagrams are valuable organizational assets that facilitate decision-making activities and communication, we consider Graphical highlights as a cognitive effective mechanism that simplifies those activities further.

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