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A study on the effects of routing symbol design on process model comprehension

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ABSTRACT

Process modeling grammars are used to create models of business processes. In this paper, we discuss how different routing symbol designs affect an individual's ability to comprehend process models. We conduct an experiment with 154 students to ascertain which visual design principles influence process model comprehension. Our findings suggest that design principles related to perceptual discriminability and pop out improve comprehension accuracy. Furthermore, semantic transparency and aesthetic design of symbols lower the perceived difficulty of comprehension. Our results inform important principles about notational design of process modeling grammars and the effective use of process modeling in practice.

1. Introduction

Process models have been recognized as an effective means for documenting and communicating business processes, especially as a means for helping to discuss different viewpoints of stakeholders in projects such as the re-design of business processes [61] or the analysis and design of process-aware information systems [45]. Indications that process models indeed make a solid contribution in this area are, for instance, provided through a study of a large number of redesign projects [26].

Process models are created using process modeling grammars — sets of graphical symbols and rules describing how to connect the graphical symbols [78]. These symbols express relevant aspects of business processes, such as the *tasks* that have to be performed, the *actors* that are involved in the execution of tasks, relevant *data*, and, notably, the *control flow logic* that describes the logical and temporal order in which tasks are to be performed. In essence, the control flow logic of a business process defines those points in the process where parallel or alternative paths might be taken, or where such paths merge. Such routing points characterize the convergence or divergence of process flows.

In process modeling grammars, convergence or divergence semantics are typically expressed through grammatical symbols named "Gateways", "Connectors, or "Splits" and "Joins" [e.g., 62,74]. These routing symbols have been subjected to much academic debate. For instance, some scholars have argued that these symbols are ill-defined from a formal perspective [e.g., 74]. They have also been found to be a key reason for modeling errors such as violation of deadlock and synchronization rules [24], and further argued to lead to understandability problems with practitioners [35].

While all available process modeling grammars support the expression of convergence or divergence semantics in a business process, they utilize different visual symbols for doing so. This difference is of crucial importance for the quality of a grammar. In other domains, it has been found that the form of visual information representation can have a significant impact on the efficiency of information search, explicitness of information, and problem solving [28], the comprehension and recall of graphical models [11,41] and even perceived usability [67].

Our objective in writing this paper, therefore, is to develop insights about the role of routing symbol design in process modeling grammars. We study how model users understand models created with different visual routing symbol designs by drawing on a theory of effective visual notations [39]. We examine four principles of routing symbol design (perceptual discriminability, pop out, semantic transparency and aesthetics) that should lead to improved process model comprehension. We then present an experiment that tests the impact of the four principles of routing symbol design on process model comprehension in terms of accuracy, efficiency and perceived difficulty. The results demonstrate that the symbol design principles affect comprehension accuracy and difficulty in different ways. Comprehension efficiency is not affected by symbol design.

We proceed as follows. First, we review the literature on factors that influence the cognitive load of process model comprehension tasks. We then discuss relevant theoretical considerations pertaining to the visual design of routing symbols in process models and identify four relevant design principles. Next we describe our research model and the experimental design of the study. We then present our data analysis and results. After that, we discuss the results and limitations. We conclude

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by summarizing the substantive as well as methodological contributions of this research.

2. Theoretical background

2.1. Cognitive load in comprehending control flow logic in process models

The division of labor in companies poses a considerable challenge to analyzing business processes in a department-spanning manner. Process models have been suggested as a means of abstraction for fostering understanding, transparency and communication of such complex processes. Even though models reduce business processes to their essential components, the creation and understanding of process models still requires high cognitive effort in itself due to the limited information processing capabilities of the human brain [76].

In light of this limitation, the key design principle for process models is to support rather than demand higher-level reasoning processes. This can, for instance, be achieved by conveying visual cues to the next logical step in reasoning about a process-related problem, or by representing process information (e.g., tasks to be performed) in the context of adjacent locations (e.g., in the context of the routing symbols that describe important business rules pertinent to the execution of the task).

Fig. 1 depicts a process model specified in the BPMN grammar [44] to illustrate how visual cueing is typically implemented in process modeling grammars. The model illustrates an E-mail voting process, based on the example given in [43]. The process consists of several activities that are executed according to a pre-defined order to reach the specific process goal (to resolve an issue). Fig. 1 shows that in this order, several divergence and convergence decisions are made, all represented by different types of gateways, in this case using a diamond shape symbol. Modeling "either/or" choices is done via so-called XOR-Split Gateways (e.g. "assess reasons for not voting" *or* skip this activity). After splitting control flow, it may be required to merge it later in the process. Exclusive choices can also be used to model repetition (loop with "election deadline has not yet passed"). Modeling concurrent activities is done via so-called AND-gateways (e.g. "review status of discussion" *and* "moderate E-mail discussion").

As the example shows, the diamond-shaped BPMN gateway symbols are intended to support the end users' interpretation and reasoning about the control flow logic of the process. While this reasoning process is fundamental to understanding the process, the body of literature on error analysis of process models suggests the existence of systematic reasoning fallacies concerning routing symbols [35]. We speculate that this may be traced back to systematic fallacies (so called 'illusory inferences') stemming from the visual design of the model or of the underlying process. These may occur when internally constructing or interpreting mental models on the basis of modeling-level connectives (like conjunctions, inclusive, or exclusive disjunctions) [22]. Concerning the example in Fig. 1, a variety of such cognitive errors could occur. Models readers could, for instance, misinterpret the AND-gateway and think both concurrent activities have to start at the same point of time, or they could confuse XOR and AND gateways if they find these gateway symbols difficult to discriminate perceptually.

Cognitive errors in reasoning about a process model relate to the *cognitive load* associated with the reasoning task. Cognitive load describes how much of the human working memory is used in learning and knowledge acquisition tasks [69]. Its importance stems from its limitations: The human working memory is the main bottleneck for cognitive tasks as its capacity is restricted to only 7+/−2 units of information at any point in time [38]. Recent literature estimates working memory capacity even lower to 3–4 elements [12]. The cognitive load of a task rises if a user has to pay attention to high amounts of relevant units of information, which in turn burdens or even overloads his/her working memory, and consequently impairs problem solving ability, learning and knowledge acquisition [69]. A variety of prior studies in the area of conceptual modeling have demonstrated that a reduction of cognitive load can lead to improvements in objective measures like comprehension [19] as well as in subjective perceptions on ease of understanding [31].

Cognitive load theory distinguishes *intrinsic* and *extraneous* cognitive load. Intrinsic cognitive load is determined by the complexity of information, i.e., the amount of elements, and their relations and interactions. In the process domain, intrinsic load pertains to the complexity of the modeled process, and thus beyond the control of the process analyst modeling a process. In contrast to that, extraneous cognitive load is determined by the way information is represented [25]. Even for exactly the same problem or task, the relative difficulty may vary depending on different problem representations [27]. Therefore, extraneous load pertains to the way a process is modeled and is thus subject to the design choices made when describing a process in a model.

Modeling design choices especially relate to notational aspects — the choice of different visual symbols for describing a process in the model. Precisely, the modifications may relate to the formal rules of a modeling grammar (its *primary notation*) or the way a specific model is visualized (its *secondary notation*) [50]. While the primary notation is normally prescribed by the specification of a modeling grammar, it has been shown that secondary notation influences process model comprehension, for instance, in terms of modularity [60], the grammatical style of text labels [36], or color highlighting [58]. These studies suggest that secondary notation is an important element in determining the extraneous cognitive load in understanding process models. Still, the research to date has focused on the secondary notation of models as a whole as opposed to the secondary notation of specific model elements — such as routing symbols, which is the focus of our work in this paper.

2.2. Effective visual design of notational symbols

To discuss the secondary notation of routing symbols in process models, we turn to a theory of effective visual notations proposed by

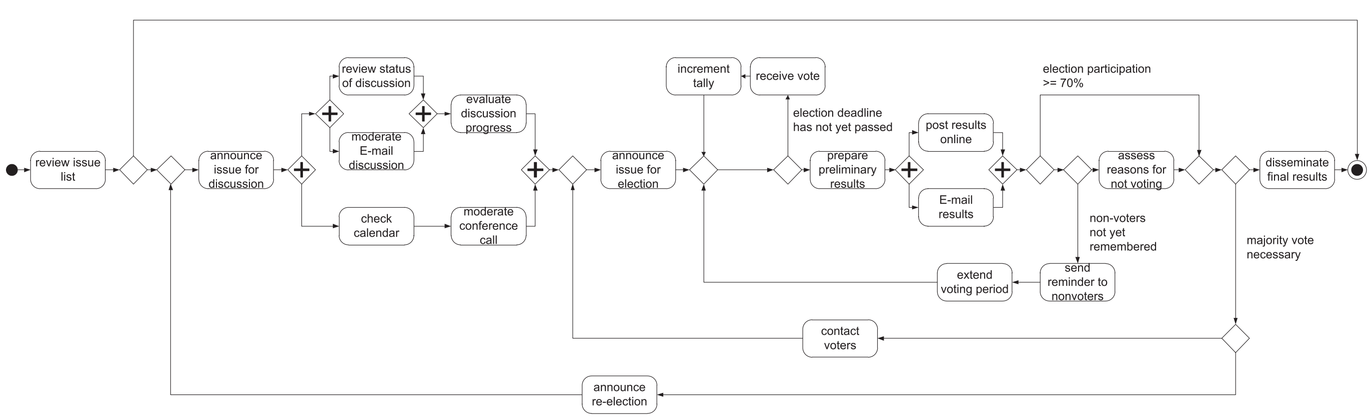

Fig. 1. Example for business process control flow logic (in BPMN).