Int. J. Human-Computer Studies 82 (2015) 96–110

Contents lists available at ScienceDirect

Int. J. Human-Computer Studies

journal homepage: www.elsevier.com/locate/ijhcs

Influence factors for local comprehensibility of process models ☆

Kathrin Figl [a,*], Ralf Laue [b]

[a] WU-Vienna University of Economics and Business, Institute for Information Systems & New Media, Welthandelsplatz 1, Building D2, A-1020 Vienna
[b] University of Applied Sciences Zwickau, Germany

ARTICLE INFO

Article history:
Received 3 May 2014
Received in revised form
22 May 2015
Accepted 26 May 2015
Communicated by E. Motta
Available online 6 June 2015

Keywords:
Deductive reasoning
Business process models
Model comprehension
Cognitive complexity

ABSTRACT

The main aim of this study is to investigate human understanding of process models and to develop an improved understanding of its relevant influence factors. Aided by assumptions from cognitive psychology, this article attempts to address specific deductive reasoning difficulties based on process models. The authors developed a research model to capture the influence of two effects on the cognitive difficulty of reasoning tasks: (i) the presence of different control-flow patterns (such as conditional or parallel execution) in a process model and (ii) the interactivity of model elements. Based on solutions to 61 different reasoning tasks by 155 modelers, the results from this study indicate that the presence of certain control-flow patterns influences the cognitive difficulty of reasoning tasks. In particular, sequence is relatively easy, while loops in a model proved difficult. Modelers with higher process modeling knowledge performed better and rated subjective difficulty of loops lower than modelers with lower process modeling knowledge. The findings additionally support the prediction that interactivity between model elements is positively related to the cognitive difficulty of reasoning. Our research contributes to both academic literature on the comprehension of process models and practitioner literature focusing on cognitive difficulties when using process models.

1. Introduction

Cognitive research has got a long tradition in the context of system development. Cognitive challenges in programming – and in reading and understanding data and process models – have been studied extensively to better match system engineering methods and human cognitive capabilities (Burton-Jones et al., 2009; Gemino and Wand, 2004; Hoc et al., 1990). Unlike computers, which can easily process program code and translated conceptual models of arbitrary size, human understanding is influenced by cognitive biases and irrational beliefs (Green et al., 2009).

Process models are conceptual models commonly applied to document and communicate processes and provide a bridge between system support and organizational requirements (Rosemann, 2006). Process modeling is a critical step in the analysis and development of automated execution support for processes. Human understanding of process models is particularly relevant because process models usually involve many tasks, which "must be enacted by a human rather than a machine" (Curtis et al., 1992, p. 75). However, the cognitive understanding and use of such models may be error-prone, especially for novices. Therefore, human interaction with process models is a relevant new research field. Several attempts have been made to identify influence factors of process model understanding (e.g., Figl et al., 2013a; Figl et al., 2013b; Mendling et al., 2012; Reijers and Mendling, 2011) and process model creation (e.g., Recker et al., 2012).

In this article, we focus on how humans reason on the basis of process models. While a variety of previous studies in this research stream have related model comprehension to global complexity metrics of process models (e.g., size, the number of specific model elements, labeling, layout,…) (Mendling et al., 2010b; Mendling et al., 2012; Reijers and Mendling, 2011), little is known about *what exactly* makes it difficult for humans to reason on the basis of a process model. It is in particular the comprehensibility of *local* properties of model structures as well as the interactivity between model elements that have not been studied in detail. Therefore, this article examines the cognitive difficulty of understanding specific parts of a process model instead of considering the model as a whole. Theoretically, it builds on cognitive load theory to explain cognitive difficulty of reasoning tasks. We propose to conceptualize comprehension of process models as deductive reasoning tasks, with the process model as the premise, and the comprehension tasks as possible conclusions drawn on the basis of the model. The article builds on a data set of comprehension questions that allows us to evaluate the cognitive difficulty of reasoning tasks and to relate this value to local metrics of the model elements involved in the task.

☆This paper has been recommended for acceptance by Henrik Iskov Christensen.
* Corresponding author. Tel.: +43 650 979 48 89; fax: +43 1 9798383.
E-mail addresses: kathrin.figl@wu.ac.at (K. Figl), ralf.laue@fh-zwickau.de (R. Laue).

http://dx.doi.org/10.1016/j.ijhcs.2015.05.007
1071-5819/

Related research efforts have already been undertaken in the area of software complexity (e.g. Yang et al., 2005). In that context, researchers have, for instance, identified measures that assign complexity values to portions of the code. By visualizing such measures in combination with code lines, the reader of a program could be alerted that a specific part of the code required special attention (Umphress et al., 2006). Likewise, knowledge gained in this study could inform modeling tool designers about process model structures with a sophisticated cognitive difficulty which enables them to design similar tool-based feedback. From a theoretical perspective, this study makes a contribution to the body of literature by providing the first empirical analysis of relevant influence factors for local comprehensibility of process models.

2. Deductive reasoning with process models

2.1. Deductive reasoning

Both comprehension and correct interpretation of models are relevant for many different tasks (Burton-Jones et al., 2009). In this context, Dumas et al. (2013, p. 63) state that "a thorough understanding is the prerequisite to conduct process analysis, redesign or execution." Asking comprehension questions is the most common way to measure comprehension of process models (e.g. Mendling et al., 2012; Reijers and Mendling, 2011). Such comprehension questions can be characterized as deductive reasoning tasks, since correct answers can be derived from general knowledge on process-flow logic and the specific process model. The questions require deductive reasoning, which is defined as the "mental process of making inferences that are logical" (Johnson-Laird, 2010, p. 8). While the "classical" psychological research on deductive reasoning has predominantly focused on propositional (based on negation and connectives as *if*, *or* and *and*) and predicate reasoning (based on quantifiers as *all*, *some* or *no*), concepts related to process logic have largely been neglected.

In deductive reasoning, a clear distinction is made between content and form. For instance, in the case of the form modus ponens with two premises (A implies B, A is true), the conclusion (B is true) is always valid if the premises are true, regardless of the premises' content. A and B can be substituted by any content and the conclusion will still be valid. For process models, this means that the verbal labels in the models and comprehension tasks could be substituted by any kind of label, e.g. abstract numbers, and the logical soundness of a conclusion would still be the same. Fig. 1 provides an example of a process model with abstract labels and four sound conclusions regarding the two model elements D and H. The conclusions refer to a single process instance, i.e. a single execution of a business case according to the rules described in the business process model. Process instances are created and executed based on the process logic defined in the model (Rinderle et al., 2004). The model uses the widespread Business Process Model and Notation (BPMN) standard. Rectangles with rounded corners depict a task. Arrows between elements indicate in which order the tasks can be executed. The diamond symbol is used to model a decision and the diamond symbol with a "+" symbol inside is used to model the start and end of parallel execution.

A typical approach in research on deductive reasoning is the use of frequency tables of the correct solutions to different logical arguments to better analyze how humans intuitively reason and to contrast their reasoning with formal logic (e.g. Beller and Spada, 2003; Braine et al., 1995). A major result of such studies is that humans do not necessarily reason logically but apply heuristics and are often subject to fallacies. For instance, according to the "post hoc ergo propter hoc" fallacy, humans assume "that a particular event, B, is caused by another event, A, simply because B follows A in time" (Damer, 2013, p. 242). Thus, humans tend to misinterpret a temporal sequence for a causal connection. By the same token, we are interested in how far humans reason logically on the basis of process models, whether specific reasoning fallacies do occur and whether some inferences are more difficult than others. In the following sections, we want to discuss several influence factors for the cognitive difficulty to reason on the basis of a process model.

2.2. Cognitive load and deductive reasoning

From a cognitive point of view, the human working memory is the main component involved in deductive reasoning with process models. The term 'working memory' "refers to a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning" (Baddeley, 1992, p. 556). If working memory is overburdened, reasoning errors are more likely to occur (De Neys et al., 2005; Süß et al., 2002).

In contrast to typical deductive arguments (in the form of two premises and a conclusion), process models as premises are not single but compound premises which makes deductive reasoning tasks fairly complex. So far, no current theory has explicitly addressed cognitive load demands in reasoning with process models. However, we can draw on theories from related areas, e.g. profound theories on the cognitive processes that are performed by programmers to understand a piece of software. The challenge to reason on the basis of a process model is fairly similar to the process of understanding facts from software code: (i) Control-flow structures such as conditional execution or loops need to be considered; (ii) Control-flow structures can be nested, and the information (the process model or the code) can be traced by the reader in an arbitrary order. Therefore, it is reasonable to assume that the process of reasoning in a business process model can be described as an adaption of the model for the process of program

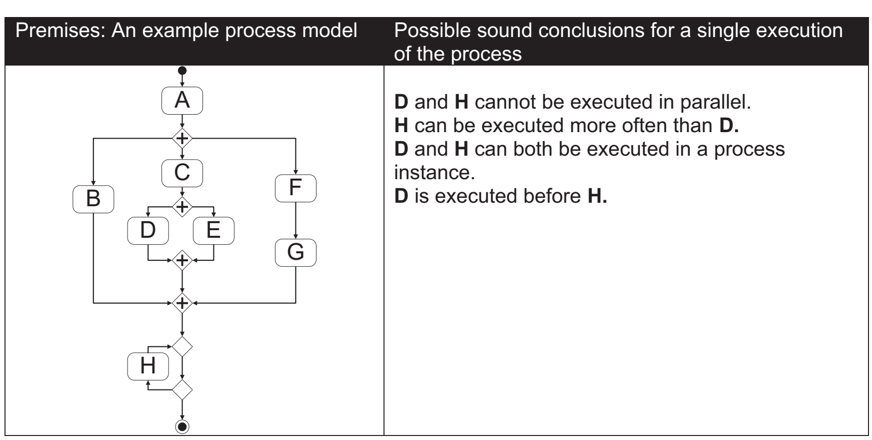

Fig. 1. Process model comprehension tasks as reasoning tasks.