Syntax Highlighting in Business Process Models

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Abstract

Sense-making of process models is an important task in various phases of business process management initiatives. Despite this, there is currently hardly any support in business process modeling tools to adequately support model comprehension. In this paper we adapt the concept of syntax highlighting to workflow nets, a modeling technique that is frequently used for business process modeling. Our contribution is three-fold. First, we establish a theoretical argument to what extent highlighting could improve comprehension. Second, we formalize a concept for syntax highlighting in workflow nets and present a prototypical implementation with the WoPeD modeling tool. Third, we report on the results of an experiment that tests the hypothetical benefits of highlighting for comprehension. Our work can easily be transferred to other process modeling tools and other process modeling techniques.

Key words: business process models, workflow nets, understandability, process modeling tool, coloring

1. Introduction

Capturing business processes in the form of graphical models has become a popular way to support the communication between business professionals and to guide the development and implementation of IT systems [11, 30]. An

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abundance of academic literature is devoted to the formal aspects of process modeling (see e.g. [33, 45, 59]), while much of the efforts in industry are geared towards standardizing the involved notations. A good example of the latter is the adoption of the Business Process Modeling Notation 2.0 as a formal OMG standard at the end of 2009.

What has received comparatively little attention are the factors that make the usage of process models effective. Because the primary purpose of process models is to facilitate human communication and problem solving – as is the case for most visual diagrams [27] – a key issue is how to improve the understanding of such models. In other words: How can process models be created such that they can be understood more quickly and accurately by human model readers? This question is of significant relevance. Many companies build their process management initiatives on large-scale process model repositories that often contain several thousands of process models [54]. Casual modelers and usual staff members create and read these models in support of their daily operations. Currently, research shows that there are serious issues with the creation and comprehension of these models [39]. Therefore, answers to the question of accurate comprehension can be expected to improve the effective use of process models in settings such as information systems development, compliance checking, and training of business professionals.

This paper's focus is on the highlighting of syntactical elements in process models to improve their understandability. More specifically, we propose the use of color to highlight process model elements that relate to one another in a way that is comparable to how pairs of opening and closing brackets in a natural sentence do. The technique of *syntax highlighting*, i.e. the coloring or emphasizing of source code in meaningful ways, has become an established feature in programming editors to support programmers in making sense of code. Despite the similarities that have been noted between process models and software code [26, 63], syntax highlighting of process models has not been introduced yet. This is all the more surprising given the wide availability of process modeling tools. At this stage, the use of color in process models is used mainly to distinguish different types of model elements, for example to distinguish events (purple) and functions (green) in Event-driven Process Chains [55], but not systematically to aid sense-making of specific process models. Against this background, the contribution of this article is threefold. First, we provide a detailed discussion of potential benefits of syntax highlighting for process model comprehension from a theoretical perspective. Second, we formalize a highlighting concept for workflow nets and demonstrate their applicability with an implementation within the open source modeling tool WoPeD. Third, and based on that implementation, we report the results of an experiment that challenges the benefits of the highlighting approach.

The structure of the paper is now as follows. In Section 2, we discuss the effects of syntax highlighting using insights from cognitive research. Section 3 defines a formal approach to highlighting for workflow nets and presents a corresponding implementation. Section 4 describes an empirical test that has been conducted to determine the effectiveness of the proposed highlighting approach. We discuss implications of our work in Section 5 and conclude our paper with Section 6.

2. Syntax Highlighting in Process Models

In this section we introduce the theoretical background of our research on syntax highlighting for process models. In Section 2.1 we discuss the concept of secondary notation and its importance for process model understanding. We use an example of a real-world process model to illustrate the potential benefits of highlighting as a mechanism of secondary notation. In Section 2.2 we investigate how different user groups might benefit from highlighting.

2.1. Color and understanding

Traditionally, conceptual models including business process models are created as an interplay between an expert in the considered domain *(domain expert)* and an expert in modeling techniques (*system analyst*) [20]. Typically, a domain expert can be characterized as someone with (1) superior, detailed knowledge of the object under consideration but often (2) minor powers of abstraction beyond that knowledge. The strengths of the system analyst are exactly the opposite. Recently, business process modeling projects have grown to company-wide initiatives in which non-expert modelers (or novice modelers) are increasingly active. Such projects can easily cover the definition and maintenance of several thousands of models. The trend towards an increasing involvement of novices in process modeling projects causes various quality issues [54]. Recent research reveals considerable weaknesses of process models from practice in terms of understanding and error probability. Many real-world process model collections have error rates of up to 30% [39]. Such quality issues have been partially attributed to the sheer complexity of certain process models [38, 40, 41, 44]. Therefore, it is an important question how readers can be better supported in understanding a process model in an accurate way.

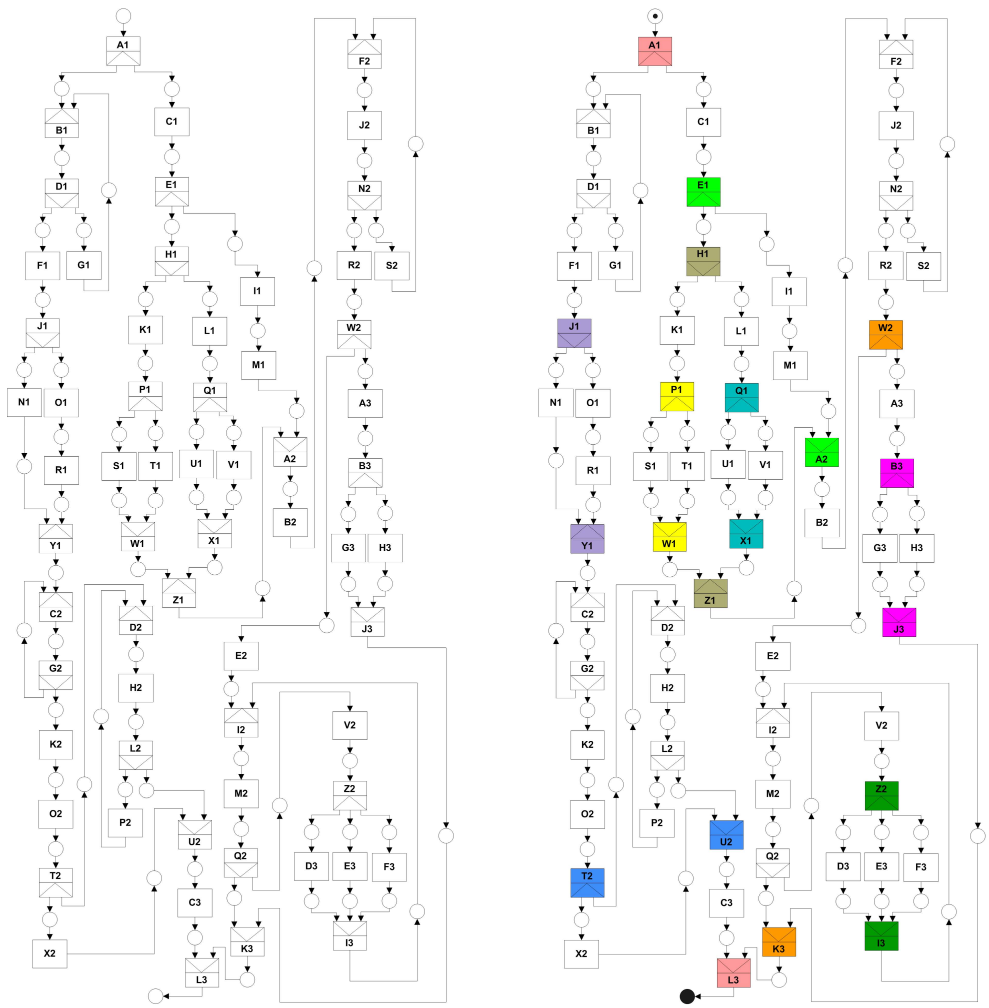
Most process models and corresponding languages are rather puristic from a visual point of view. Hardly any highlighting is used except for Event-driven Process Chains in which sometimes events (purple) and functions (green) are distinguished by color. The research by Bertin on the semiology of graphics identifies eight distinct visual variables that can be used to encode graphical information [4]. Color is considered to be one of the most effective of these variables. The human visual system is able to recognize color quickly [37]. Distinctions between different colors can be detected accurately and three times faster than between shapes [36]. Therefore, Moody criticizes that color is hardly used by modeling notations to distinguish notation elements [46]. These insights clearly point to the attractiveness of using color in a systematic way to improve the understanding of process models.

Furthermore, the Cognitive Dimensions Framework (CDF) by Green and Petre provides the background to postulate a way to sensibly apply coloring [23, 24]. The CDF has been highly influential in language usability studies and numerous publications have been devoted to its further development, see its discussion in [5]. It provides a set of characteristics to evaluate a wide variety of notations, e.g. spreadsheets, style sheets, diagrams, etc. Specifically, process modeling languages have been analyzed to be "abstraction-hating", because they do not provide any mechanism to group activities . This leads to several problems in terms of cognitive processing as it is not directly visible where a certain sub-component of a process model starts and ends. As a result, the inside of a component cannot be ignored when considering behavioral aspects around it and it is hard to neglect a sub-component's environment when its internal aspects are investigated. Additionally, in terms of the CDF the start and end nodes of sub-components are examples of long-range "hidden dependencies". In a process model, it is very common that a particular type of start node calls for a similar type of end node. However, the larger and more complex a model gets, the more difficult it is to determine which start and end nodes belong to one another. This is problematic since identifying matching entry and exit nodes of a component helps the model reader in terms of information hiding [49, 53].

Motivated by the discussed shortcomings of process models as a visual notation according to the CDF and the potential power of color as a visual variable mentioned eaerlier, it seems attractive to focus on the highlighting of entry and exit nodes of sub-components. Such nodes typically reflect a particular routing semantics. In a workflow net context, they are called operator transitions. We will use this term already here; its precise definition will be part of the section on our formal highlighting approach.

How exactly highlighting may be used to facilitate information hiding is illustrated in Figure 1. It shows two versions of a real-world process model that has been made available to us through a cooperation with the Dutch branch of Sogeti[1], a large ICT service provider. The process captures how within one of Sogeti's clients, a multinational bank, existing credit facilities are updated. This is required at times, for example because of changes in the preferences of the account holders or in the commercial circumstances. The process involves the execution of various checks by bank clerks, as well as updates they have to

[1] http://www.sogeti.com/



(a) (b)

Figure 1: Changing a credit facility process without (a) and with (b) highlighting

carry out in IT systems. Sogeti professionals created a model for this process to use it as a basis for discussion with bank employees on how to improve the business process in question.

This process model is captured as a *workflow net* [58]. The model captures 63 different transitions representing business *activities* (also often referred to *tasks*), 75 places indicating *milestones* in the process, and 157 arcs specifying the *paths* along these elements. Also notable are the 30 *operator transitions* (XOR-splits, XOR-joins, AND-splits and AND-joins), which capture how alternative and concurrent paths are spawned off and joined again at different stages in the process. A complex aspect of this model is that it is represented in a compact form; the modelers wanted it to fit on a single sheet of A4 paper so that it could be easily printed and reproduced. As a result, some arrows are running bottom-up, which could easily be interpreted as iterations in the model while this is not always so. For, example, the arrow from *B2* to *F2* simply indicates sequential progress instead of a step back.

While the formal structures of both versions of the process model are the same, there is a notable difference in the way how matching operator transitions are highlighted. Cognitive research into program comprehension has coined the terms primary notation and secondary notation to describe this phenomenon. The modeling notation as a formal set of symbols is defined as *primary notation*. Primary notation specifies the semantics of all graphical elements of a particular notation, such as Petri nets. This primary notation of Petri nets is defined using particular shapes for the different syntax elements. In the model with highlighting, it can be seen that some sets of operator transitions have received the same color, for example *E1* and *A2* that are both highlighted in green. Transition operator *E1* – an AND-split – signifies that two concurrent paths are initiated after its execution, one of them starting with transition *H1*, the other with transition *I1*. By enriching the process model with information beyond the formal notation (e.g. color, line strength, etc.), the reader may access the information captured in the model with a differing degree of ease [50]. Visual cues, which are not part of a notation, are known as *secondary notation* [51]. These visual cues have a twofold advantage. First, they help to identify a decomposition of the process model into components, which provides for information hiding when the overall behavior of the process model is analyzed. Second, the usage of color helps to interpret secondary notation quickly, as color can be processed by the human visual system much faster than for instance shape [36]. These facts should result in better comprehension performance, which is typically measured in terms of accuracy and efficiency [7, 21]. Therefore, we formulate the following hypotheses in relation to accuracy and efficiency of comprehension.

H1 The use of colors to highlight matching operator transitions will have a significant positive impact on understanding accuracy.

H2 The use of colors to highlight matching operator transitions will have a significant positive impact on understanding speed.

2.2. Highlighting, understanding, and expertise

Prior research has shown that users tend to have serious problems with understanding how different operator transitions interplay and which ones belong together. It comes as no surprise that model readers with different characteristics face understanding problems to a different extent. For instance, it has been observed that readers with a solid background in Petri net concepts [41] and theoretical concepts of process models altogether [43] show a much better understanding performance than others. Also, other personal factors like the duration and intensity of process modeling experience have been identified as factors of process model understanding in prior research [52]. Altogether, modeler expertise is a critical issue for process modeling projects [3].

Archetypically, novices and experts in process modeling can be distinguished. The notion of expertise has been related to different aspects. As an adaptation of [10, 16], we can state that it is established by "the amount and complexity of knowledge gained through extensive experience of activities" in process modeling [16] or by acquiring "vast amounts of knowledge and the ability to perform pattern-based retrieval" related to process models [10]. The difference between novices and experts in process model comprehension can be explained based on the Adaptive Control of Thought architecture proposed by Anderson [2]. According to this architecture, the human working memory interacts with declarative and production memory, which both the latter have distinct features. While declarative memory stores and provides access to facts that we explicitly know, the production memory holds rules of interference, which can be used in problem solving. The production memory of an expert contains a much richer set of production rules than the one of a novice. In relation to process models, an expert would likely know productions that help to hide information, for instance, to ignore components when interpreting the overall behaviour of a process model. While both novices and experts will presumably benefit from color highlighting, it is likely that their differences in production memory will result to a difference in the extent of this effect. Both an unhighlighted and a highlighted process model are informationally equivalent, i.e. they capture the same information on a process [34, 56]. On the other hand, they are not computational equivalent because they differ in the ease with which information can be deducted from them. For a novice, this computational benefit is great as a novice lacks suitable production rules to inspect a process model. For an expert, the computational improvement is smaller which she possesses production rules to manage the complexity of a process model. Therefore, it is not a surprise that expert modelers have been observed to focus on relevant graphical elements, recognize patterns and disregard irrelevant information [50], while novices tend to lack reading and search strategies, which result from modeling experience and extensive learning. As a result, we expect highlighting of matching nodes in a process model to be a significant aid for novices to read the models and their control flow semantics. Experts, in turn, can much easier identify patterns of matching operator transitions, a skill that is also referred to as perceptual expertise [25]. Accordingly, the highlighting support helps them to identify patterns faster they already know, which is of less value to them in comparison to novices. As a consequence, their performance increase should be less strong in comparison to novices. Therefore, we formulate the following hypotheses:

H3 The highlighting of matching operator transitions will have a significant positive impact on understanding accuracy for novices.

H4 The highlighting of matching operator transitions will have a significant positive impact on understanding speed for novices.

H5 The highlighting of matching operator transitions will have a significant positive impact on understanding accuracy for experts.

H6 The highlighting of matching operator transitions will have a significant positive impact on understanding speed for experts.

H7 The highlighting of matching operator transitions will be more significant for understanding accuracy of novices than of experts.

H8 The highlighting of matching operator transitions will be more significant for understanding speed of novices than of experts.

Before we can evaluate these hypotheses, we first have to explicitly define how the syntax highlighting approach for process models can work. This is the subject of the next section.

3. A Formal Approach to Syntax Highlighting

In this section we formalize a formal approach to highlighting matching entry and exit nodes in nets that are inspired by so-called workflow nets. Section 3.1 defines some Petri net concepts, which are an important basis for the notion of workflow nets. Section 3.2 presents the highlighting approach as we have implemented it in WoPeD.

3.1. Petri Nets and Workflow Nets

A *Petri net* $N = (P, T, F)$ is a directed, bipartite graph where P is a set of nodes called *places*, T a set of nodes called *transitions* and $F \subseteq (P \times T) \cup (T \times P)$

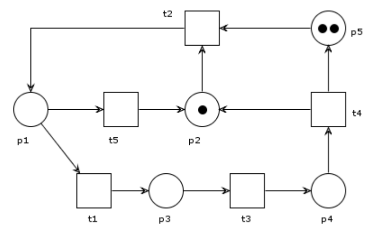


Figure 2: A simple Petri net

a binary *flow relation.* For a node $n \in P \cup T$ of a Petri net, we call $\bullet n = \{m \in P \cup T \mid (m,n) \in F\}$ the *preset* of n and $n\bullet = \{m \in P \cup T \mid (n,m) \in F\}$ the *postset* of n. Figure 2 shows a Petri net with $P = \{p_1, p_2, p_3, p_4, p_5\}$, $T = \{t_1, t_2, t_3, t_4\}$, $F = \{(p_1, t_1), (t_1, p_3), ...\}$. Here, for example, $\bullet t_2 = \{p_2, p_5\}$ is the preset of t_2 and $t_3\bullet = \{p_4\}$ is the postset of t_3.

A sequence of nodes $\pi = \langle n_1, ..., n_k\rangle$ of a Petri net where $(n_i, n_{i+1}) \in F$ for $i \in [1..k-1]$ is called a *path* from n_1 to n_k. A path $\pi = \langle n_1, ..., n_k\rangle$ is called *elementary path*, if it does not contain the same node more than once, i.e. for each two nodes n_i and n_j always holds $n_i \neq n_j$. In Figure 2, $\langle p_1, t_1, p_3, t_3, p_4\rangle$ is an example for an elementary path; $\langle p_1, t_5, p_2, t_2, p_1\rangle$ is an example for an non-elementary path. Since elementary paths contain each visited node only once, they can be represented as plain sets instead of sequences. For technical reasons, we define an *alphabet operator* α mapping an elementary path sequence to a plain set of nodes: $\alpha(\langle n_1, ..., n_k\rangle) = \{n_1, ..., n_k\}$.

In the area of business process modeling, Petri nets have been used as the basis for so-called *workflow nets.* By now, these have become widely-used to capture business processes in a graphical form. Workflow nets were originally introduced in [59] and have been used in many applications and publications ever since. Inspired by the more recent workflow net variant that is being presented in [58], a workflow W net can be formally defined as a tuple $(P, T, F, T_{AS}, T_{XS}, T_{AJ}, T_{XJ})$ with the following properties:

- (P, T, F) is a Petri net

- $T_{AS} \subseteq T$, $T_{XS} \subseteq T$, $T_{AJ} \subseteq T$, $T_{XJ} \subseteq T$ are mutually disjoint sets of *operator transitions* called AND-split, XOR-split, AND-join and XOR-join transitions respectively

- $|\{p \in P : \bullet p = \emptyset\}| = 1$, i.e. there exists exactly one place with empty preset (called the *source place*, usually denoted by i)

- $|\{p \in P : p\bullet = \emptyset\}| = 1$, i.e. there exists exactly one place with empty postset (called the *sink place*, usually denoted by o)

- $\forall t \in T : |\bullet t| > 0 \wedge |t \bullet| > 0$, i.e. all transitions have a non-empty preset as well as a non-empty postset

Figure 3 shows an example of a workflow net that uses all four types of operator transitions. The corresponding decorations are shown on the transition symbol of $T_{AS} = \{register, sign\}$, $T_{XS} = \{evaluate, check\}$, $T_{AJ} = \{process, archive\}$ and $T_{XJ} = \emptyset$. Here, *register* is used to represent a point after which $send\ form$ and *evaluate* can be carried out simultaneously (or in an arbitrary order); *evaluate* itself signifies that a decision is to be made between two paths. Note that in a classical Petri net an XOR-join is represented as a place that has more than one preset element, e.g. $form\ ok$ and *acceptable* are such places. Analogously, in a classical Petri net places with more than one postset element are equivalent to XOR-splits. We will include both types of XOR representations in our workflow nets and consider them as equivalent. However, we will refer to the use of decorated transitions for XOR-splits and –joins as *explicit* representations and the use of places for these operators as *implicit* presentations. At this point, it is important to note that XOR and AND operators form the core of the routing logic that is supported by most process modeling popular languages, e.g. BPMN, UML activity Diagrams, and EPCs.

A workflow net $W = (P, T, F, T_{AS}, T_{XS}, T_{AJ}, T_{XJ})$ can always be uniquely extended by adding a transition t^* connecting the sink place o with the source place i. We call t^* the *short-circuit transition* of W. Analogously, we call the net

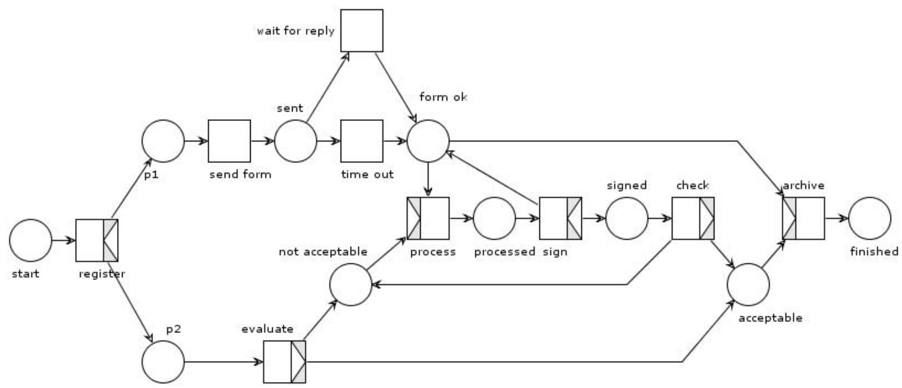


Figure 3: A workflow net

W^* that is represented by the tuple $(P, T \cup \{t^*\}, F \cup \{(o, t^*), (t^*, i)\}, T_{AS}, T_{XS}, T_{AJ}, T_{XJ})$ the *short-circuited net* of W. Note that W^* is not a workflow net according to the above definition, because it has neither a source nor a sink place. We will use it mainly for technical reasons.

For technical reasons too, we need to be able to reason about the prefix or precursor of a workflow net, as it exists at intermediate stages of an interactive modeling session. For this reason, we introduce a weakened version of the above definition of a workflow net. Specifically, we call $N = (P, T, F, T_{AS}, T_{XS}, T_{AJ}, T_{XJ})$ an *operator-extended net* in which (P, T, F) is a Petri net. As will be shown, this definition will allows us to highlight operator transitions within incomplete workflow nets. Note that the class of workflow nets is a subset of the class of operator-extended nets, i.e. each workflow net is an operator-extended net.

Finally, we will assume that all operator transitions are used in a sensible way. Specifically, each *split* transition has a non-singleton postset, each *join* transition has a non-singleton preset, and each non-operator transition has a singleton preset and postset. Formally, we call a given operator-extended net $N = (P, T, F, T_{AS}, T_{XS}, T_{AJ}, T_{XJ})$ *operator-normalized*, if the following holds:

- $\forall t \in T_{AS} \cup T_{XS} : |t\bullet| > 1 \land |\bullet t| \leq 1$

- $\forall t \in T_{AJ} \cup T_{XJ} : |\bullet t| > 1 \wedge |t\bullet| \leq 1$
- $\forall t \in T \setminus (T_{AS} \cup T_{AJ} \cup T_{XS} \cup T_{XJ}) : |t\bullet| \leq 1 \wedge |\bullet t| \leq 1$

We are now able to more formally express the notion of *matching operator pairs* that we aim to highlight as a way to improve the comprehension of the overall model. Our definition is a generalization of the concept of PT/TP-handles [18]:

In an operator-extended net $N = (P, T, F, T_{AS}, T_{XS}, T_{AJ}, T_{XJ})$, a pair of nodes $(n_1, n_k) \in (P \cup T) \times (P \cup T)$ is called a *matching operator pair* iff

- $n_1 \in T_{AS}$ and $n_k \in T_{AJ}$ or $n_1 \in P \cup T_{XS}$ and $n_k \in P \cup T_{XJ}$
- there are at least two elementary paths π_1 and π_2 leading from n_1 to n_k with $\alpha(\pi_1) \cap \alpha(\pi_2) = \{n_{1,} n_k\}$

The intuition behind this definition is that if two or more different paths connect two nodes then these nodes signify the start and end of a noteworthy sub-component of the overall routing logic. Note that the notion of matching operator pairs is not restricted to nets that are completely or even highly block-structured. In the next section, we will focus on the implementation of the idea to highlight matching operator pairs.

3.2. Implementation in WoPeD

WoPeD[2] is a Java-based open source tool supporting the modeling of plain Petri nets as well as that of workflow nets. Several publications have accompanied the emerging development, e.g. [13, 14]. In the most recent release, the highlighting of matching operator pairs is supported as a switchable option. If enabled, the current editor content is constantly monitored for user-inflicted changes by executing a detection algorithm assigning each matching operator pair a distinguishable color from a predefined palette.

Figure 4 shows an operator-normalized workflow net with a total of four matching operator pairs:

[2] http://www.woped.org/

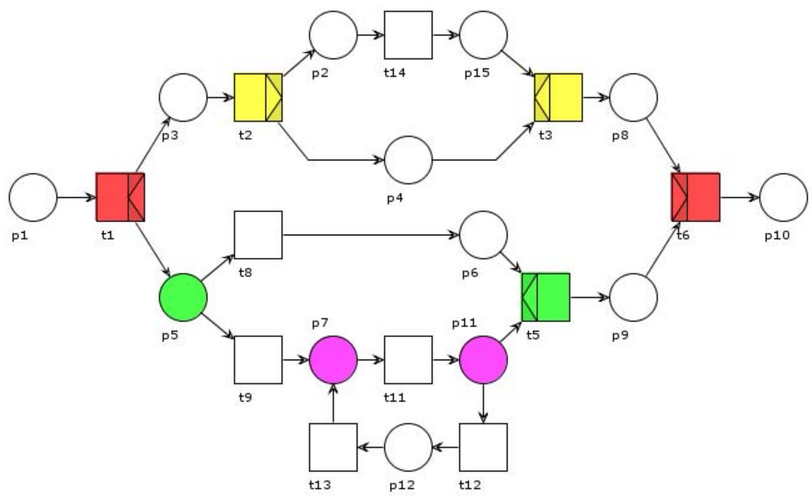


Figure 4: Highlighted matching operator pairs

- (t_1, t_6) is an AND-split/AND-join pair (red)
- (t_2, t_3) is an explicit XOR-split/explicit XOR-join pair (yellow)
- (p_5, t_5) is an implicit XOR-split/explicit XOR-join pair (green)
- (p_{11}, p_7) is an implicit XOR-split/ implicit XOR-join pair (magenta)

Note that for determining the colors it is not necessary that the editor contains a workflow net; an operator-extended net will be sufficient. For simplicity and without loss of generality, we additionally assume that nets are operator-normalized, i.e. all operators have a "sensible" branching context. Under this assumption, the set of candidate pairs to be considered as potentially matching operators can be restricted to pairs (x, y) where either (1) x is an XOR-split (or a place with a non-singleton postset) and y an XOR-join (or a place with a non-singleton preset) or (2) x an AND-split and y an AND-join. Additionally, if the current editor content is detected to conform to the properties of a workflow net, the short-circuited version of the net is considered to find additional pairs of matching operators. For example, (p_{11}, p_7) in Figure 4 can only be detected by considering the short-circuited version of the net. Note that as long as the net under construction is not a workflow net, the detection of matching operator pairs is not necessarily complete yet all detected pairs are indeed matches.

Each candidate pair of nodes is checked for being a matching operator pair by applying the Ford and Fulkerson *max-flow-min-cut* algorithm [19]. This algorithm can be used to determine the maximum flow in a flow network between its source and sink. Our implementation applies this algorithm in the context of an operator-extended net by considering for each candidate pair its first (split) element as a source and its second (join) element as a sink. Furthermore, the maximum capacity for each edge is set to 1 and the direction of each edge determines the flow direction. If the *max-flow-min-cut* algorithm establishes that the maximum flow between the two elements of a candidate pair exceeds 1 then this indicates a minimum of two different elementary paths between them. In other words, in such a case a matching operator pair is found. In the example of Figure 4, the maximum flow between p_5 and t_5 is exactly two since there is a capacity of 1 along the path $\langle p_5, t_8, p_6, t_5 \rangle$ and an additional capacity of 1 along path $\langle p_5, t_9, p_7, t_{11}, p_{11}, t_5 \rangle$.

Our implementation of the *max-flow-min-cut* algorithm is derived from the one introduced in [29], with the modification to select nodes based on breadth-first-search [15]. With this modification, our algorithm has a complexity of $O(|D \cup D'||A|^2)$. The complete algorithm executes the *max-flow-min-cut* algorithm $|(P \cup T) \times (P \cup T)|$ times and therefore runs in polynomial time with $O(|(P \cup T)|^3|F|^2)$.

At this point, it should be considered that the membership of a node as an element of a matching operator pair is not exclusive. Pairs of matching operators may exist that overlap, in the sense that they share common nodes. Since only a single color can be assigned to each node at a time, it appears sensible to color all overlapping pairs of matching operators in the same color. To establish a common highlighting of overlapping operator pairs, a "clustering" is implemented as shown in Algorithm 1.

To illustrate this algorithm, we start with the example set of matching operator pairs (t_1, t_6), (t_2, t_3), (p_5, t_5), (t_8, t_6), (p_{11}, p_7) for the workflow net in

Algorithm 1 Computation of matching operator clusters

Let $Op_C \subseteq \mathcal{P}(P \cup T)$ be a set of sets where each element is the set representation of a matching operator pair (i.e. each pair (x, y) is contained as a set $\{x, y\}$)

while $\exists op_1, op_2 \in Op_C : op_1 \neq op_2 \wedge op_1 \cap op_2 \neq \emptyset$ **do**

  $op := op_1 \cup op_2$

  $Op_C := Op \backslash \{op_1, op_2\} \cup \{op\}$

end while

return Op_C

Figure 5. The conversion to a set of sets yields:
$Op_C = \{\{t_1, t_6\}, \{t_2, t_3\}, \{p_5, t_5\}, \{t_8, t_6\}, \{p_{11}, p_7\}\}$. In the first iteration, $\{t_1, t_6\}$ and $\{t_8, t_6\}$ are combined into $\{t_1, t_6, t_8\}$. After the separate elements have been removed and the combined set is added, no overlapping elements are left in Op_C. Each of the remaining elements is Op_C is now a *cluster* of the underlying net. All elements in a cluster will be assigned with the same color. As can be seen in Figure 5, indeed, t_1, t_6, and t_8 are colored the same. The color palette itself can be created via a settings dialog and configured by the user with individually chosen color values, as can be seen too in Figure 5.

Note how this workflow net in Figure 5 is a slightly extended version of the block-structured net that is shown in in Figure 4: Transition t_8 is turned into an AND-split and an additional place p_{15} is added between transitions t_8 and t_6. As such, this example also illustrates how the coloring approach is applicable to both block-structured and non-block-structured nets.

4. Research Method

We set up an experiment to investigate the effectiveness of our proposed highlighting approach by testing the hypotheses of Section 2. Section 4.1 presents our research design and a description of how the experiment was conducted. Section 4.2 summarizes the results of the experiment.

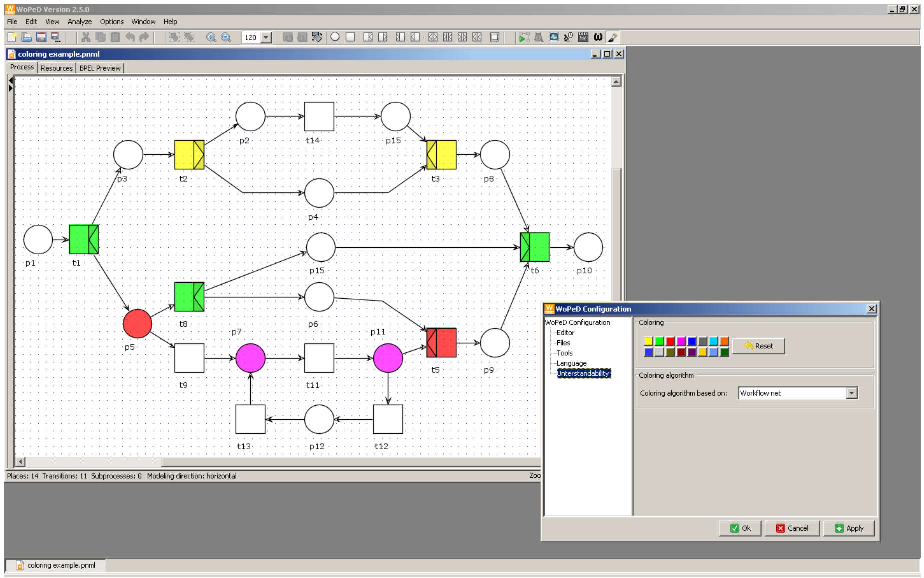


Figure 5: A settings dialog for the color palette

4.1. Research Design and Conduct

To design the experiment, we have been following the recommendations given in [32, 66]. This section describes the subjects, objects and selected variables of our experiment, introduces our hypotheses, and presents the instrumentation and data collection procedure.

The *subjects* are 62 experienced modelers both from industry and academia (experts) and 41 students following a graduate course on Business Process Management at Eindhoven University of Technology (novices). The professionals were recruited from two Dutch consultancy organizations and three international research groups with a special focus on Business Process Management. All participated voluntarily. The central *object* that is used in the experiment is the process model that was introduced in Figure 1. Its two variants – with and without highlighting – were used to represent two levels of our primary *factor* of interest, i.e. the highlighting of matching operator pairs. Furthermore, we recorded the *factor* expertise on two levels: expert and novice. In the experiment, two *response variables* were used. First, the number of correct answers to a set of closed questions was used as the indicator of *understanding accuracy*. The time that was taken by the respondents to answer this set questions is the second response variable, indicating the *understanding speed*.

To investigate the hypotheses of Section 2, an on-line instrument was developed to conduct a self-administered experiment. The instrument was developed with PHP 5.1.4 and JavaScript and ran on an Apache Web Server hosted at Eindhoven University of Technology. The instrument leads the participant through three successive parts:

1. Introduction: In this first part, the purpose of the experiment is explained as well as the expected effort to complete it. Furthermore, an explanation of the workflow net notation is provided. Finally, it is explained that participants are expected to answer the questions accurately and as fast as possible.
2. Demographic information: The participant is requested to provide information on her background, experience with process modeling, and familiarity with the workflow net notation.
3. Experiment: Depending on a random draw, the respondent is assigned with an equal probability to either the model with or without highlighting support. In total, a set of nine questions is provided one after another to the respondent. Questions could not be skipped. At all times, a legend with an explanation on the workflow net notation is visible.

The screenshot in Figure 6 gives an impression of the look and feel of the instrument.

The closed questions from one of our previous experiments [41] were used in this experiment. An analysis of these questions and the data obtained in that work provided a value of 0.675 for Cronbach's alpha. This can be considered as an acceptable indication for internal consistency, for example when compared with other empirical research in the context of business process oriented research [28]. The questions cover issues with respect to:

- *concurrency*, e.g. "Can tasks A and B be be executed at the same time

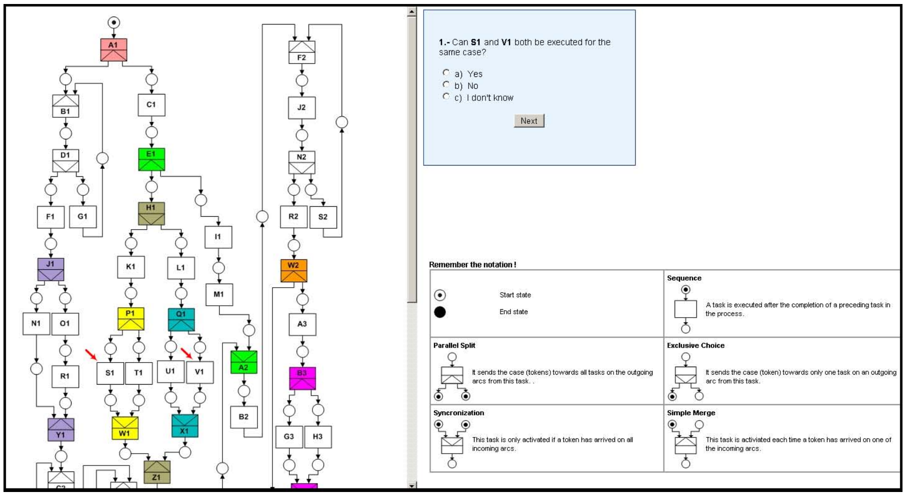


Figure 6: Screen shot of the on-line instrument

for a case?”

- *exclusiveness*, e.g. “Can tasks A and B both be executed for the same case?”
- *order*, e.g. “If task A is executed for a case, must then always task B be executed for the same case?”
- *repetition*, e.g. “Can task A be executed more than once for the same case?”

For all questions, the respondents were offered the answer categories ‘yes’, ‘no’ and ‘do not know’.

4.2. Results

Before testing the hypotheses, the quality of the data was analyzed. From the total of 103 answer sets that were provided for the questions on the models (both with and without highlighting), 26 were incomplete. Although the tool did not allow any questions to be skipped, people always had the opportunity to stop the experiment at any time by simply closing their browser. All data being part of an incomplete set of answers was removed. Furthermore, in line with [22],

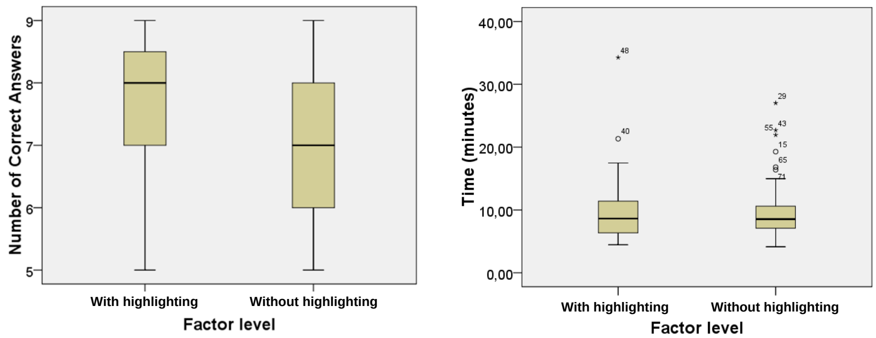


Figure 7: Boxplots for *understanding accuracy* (number of correct answers) and *understanding speed* (time)

quality checking was applied to the data. We expected expert modelers to be able to at least correctly answer 5 out of 9 questions (55%) and novices at least 4 out of 9 questions (44%). Results below these thresholds were considered to reflect a serious lack of knowledge and/or commitment. As a result, 7 additional answer sets had to be removed. The latter is a relatively small number, which is an indication for the overall high quality of the raw data. In total, 70 answer sets were taken into account for the data analysis ($= 103 - (26 + 7)$).

General Effect of Highlighting: The 70 answer sets were explored for the response variables of interest, *understanding accuracy* and *understanding speed*. The subjects on average provided 7.21 correct answers for the total of 9 questions (80%) with a minimum of 5 and a maximum of 9. On average, it took respondents a little over 10 minutes to answer the questions, with a minimum of approximately 4 minutes and a maximum of approximately 34 minutes. Application of the Kolmogorov-Smirnov test [57] indicated that the distributions for both variables differ significantly from the normal distribution, which may be due to the limited size of the data set. Box plots that show the distribution of the response variables, differentiating between the factor levels *with* and *without* highlighting, are provided in Figure 7.

Inspection of the box plots does not point at *understanding speed* being affected strongly by highlighting, i.e. the medians and distributions are quite

Table 1: Two-tailed Mann-Whitney test for Hypotheses **H1** and **H2**

Hypothesis	p-Value	Support
H1 Highlighting → Accuracy	0.049	✓
H2 Highlighting → Speed	0.583	∅

similar. The *understanding accuracy* for subjects provides a somewhat other picture, with the number of correct answers being slightly higher for those subjects that used the process models with highlighting support for answering the questions. A corresponding non-parametric Mann-Whitney test [57] confirms these observations. This type of test is appropriate in the light of the non-normality of the data. The Mann-Whitney test is applicable to experiments that consist of one factor and two treatments with a completely randomized design [66], as is the case here. Table 1 reports the significance levels. Accordingly, we find support for Hypothesis **H1** (i.e. there ia positive impact on understanding accuracy), but not for Hypothesis **H2** (i.e. there is no positive impact on understanding speed).

Effect of Coloring for Novices and Experts: A more detailed data analysis that distinguishes between novices and experts is provided in Table 2. From the table, various differences can be distinguished between the analyzed statistics. For example, experts on average perform better than novices: They have higher numbers of correct answers and are faster in responding to the questions. Also notable is that novices on average correctly answer 7.08 questions when provided with highlighting support but only 5.92 without that support, which would be in line with Hypothesis **H3**. To examine all the hypotheses we stated, we used the non-parametric Mann-Whitney test separately of the novice sub-sample and the expert sub-sample. The results are shown in Table 3.

As can be seen, a significant difference between the availability of highlighting support and the lack thereof exists and relates to the *understanding accuracy* (number of correct answers) for novices. Indeed, the difference we mentioned between the 7.08 and 5.92 correct answers on average is not likely to be a mat-

Table 2: Descriptive statistics for *understanding accuracy* (number of correct answers) and *understanding speed* (time)

		Novices		**Experts**	
	Statistics	With highlighting	Without highlighting	With highlighting	Without highlighting
Number of Correct Answers	N	13	13	18	26
	Mean	7.08	5.92	7.89	7.46
	Median	7.00	6.00	8.00	7.50
	Std. Dev.	1.188	.954	1.231	1.140
	Skewness	-.524	.854	-1.041	-.161
	Kurtosis	-.105	.221	0.289	-.697
Time (minutes)	N	13	13	18	26
	Mean	102.680	115.449	98.796	96.231
	Median	79.333	99.167	87.083	81.917
	Std. Dev.	795.681	486.906	445.450	536.402
	Skewness	2.587	.694	1.471	2.251
	Kurtosis	7.621	.224	1.606	4.683

Table 3: Two-tailed Mann-Whitney test for Hypotheses **H3** to **H8**

Hypothesis	p-Value	Support
H3 Highlighting → Accuracy of Novices	0.017	✓
H4 Highlighting → Speed of Novices	0.139	∅
H5 Highlighting → Accuracy of Experts	0.184	∅
H6 Highlighting → Speed of Experts	0.535	∅
H7 Accuracy of Novices << Accuracy of Experts	0.017 << 0.184	✓
H8 Speed of Novices << Speed of Experts	0.184 << 0.535	✓

ter of chance. In other words, whether a *novice* model reader is considering a process model with or without highlighting will make a significant difference in terms of her *understanding accuracy.* In fact, that accuracy is then higher. The *understanding speed* for novices, however, does not differ significantly. Furthermore, highlighting is *not* a distinguishing factor for the performance of the experts.

In summary, we find support for the general benefit of highlighting for the understanding accuracy (**H1**), in particular for novices (**H3**). The effect is not significant for experts though (**H5**). Effects on understanding speed appear to be negligible (**H2**, **H4**, **H6**). Still, novices appear to benefit more than experts in terms of both understanding accuracy and understanding speed (**H7-H8**).

5. Discussions and Implications

In this section we discuss the results and the implications of our research.

5.1. Discussion of Results

The results of the experiment have to be interpreted in terms of significance and strength of the noted effect. Furthermore, our distinction between novices and experts has to be reflected upon.

Personal factors have been identified as factors of process model understanding in prior research [41, 43, 52]. In this experiment we considered a classification of novices and experts based on participants being students or professionals (either from academia or industry). In general, the distinction between novices and experts is not so straight-forward and related to notions that are difficult to measure, like "the amount and complexity of knowledge gained through extensive experience of activities in a domain" [16] or "the result of acquiring [...] vast amounts of knowledge and the ability to perform pattern-based retrieval" [10]. Furthermore, it is important to notice that task-specific experience is often a better predictor of performance than expertise in general [6]. The fact that the mean values in our experiment are conclusive supports the appropriateness of our classification: experts without highlighting are still faster and more accurate than novices with highlighting in Table 2.

The experiment showed that the highlighting was of greatest benefit to the *accuracy* of *novices*, such that it was the single significant effect. This observation is in line with research that establishes modeler expertise as a critical issue for process modeling projects [3]. Petre observed in her research on secondary notation that novices tend to lack reading and search strategies which result from modeling experience and extensive learning [50]. Syntax highlighting in our experiment is a significant aid for novices to read the models and their control flow semantics. Therefore, it is no surprise that their performance in terms of accuracy is improved. Experts, in turn, can much easier identify patterns of matching operator transitions, a skill that is also referred to as perceptual expertise [25]. Accordingly, the highlighting helps them to identify patterns they already know. As a consequence, the performance increase is too small to be significant in our experiment.

It is arguable that the effect of highlighting on performance of both experts and novices might have been stronger if the models had been more complex. It is well known from prior research that more complex models are more difficult to understand [38, 41]. Several metrics have been proposed to measure different dimensions of complexity of a process model, e.g. in [1, 8, 9, 35, 38, 44, 47, 48, 62]. The models we used in the experiment are fairly structured such that a split operator most often has a direct join counterpart. Such structured models are rather easy to understand for experts. The highlighting effect might have been more effective also for experts if the models had been more unstructured. The reader may recall that, indeed, the identification of matching operator pairs is also possible in unstructured nets. Additionally, it might be argued that models need to be much larger before highlighting starts to have a significant effect on experts' performance.

5.2. Implications

The experiment and the results have implications for research and practice.

With this work we have shown the potential of secondary notation to improve process model understanding. We have focussed on the highlighting of matching operator pairs. Further research is needed to investigate the effect of other types of secondary notation. In particular, techniques from automatic graph drawing have been discussed regarding their support of understanding, e.g. in [65]. A dedicated discussion of automatic layouting of process models and their benefit to comprehension is missing so far. For such a research endeavor it is important to consider modeling expertise and its interplay with secondary notation. While process modeling expertise has been considered by some studies on process model comprehension [41, 43, 52], there is a need for further research on establishing a more detailed foundation for this notion.

In this article, we also demonstrated the feasibility of automatic highlighting both by providing a formalization and by an implementation within the Petri net modeling tool WoPeD. The general concepts of our approach can be easily extended to other activity-oriented process modeling languages (e.g. UML Activity Diagrams [17], EPCs [60], or BPMN [12]). Even for those languages that do not directly build on token passing semantics, graph parsing techniques can be used to define colors based on so-called single-entry-single-exit components [31, 64]. Therefore, our highlighting approach can be directly included in industry process modeling tools to improve process model comprehension.

6. Conclusion

This paper addresses the problem of how process model users can be better supported in the sense-making of a model. We adapted the concept of syntax highlighting from software engineering and applied it to workflow nets, a formalism that is frequently used for business process modeling. Our contribution is a theoretical discussion of the benefits of such highlighting, a formalization of the highlighting problem along with a prototypical implementation, and a thorough experimental study on the effects of highlighting on comprehension performance. Due to the structural and semantic similarities between workflow nets and other process modeling languages, the results from this research can be easily applied in other process modeling tools.

Our future work is in line with some of the open issues we already noted. We plan to conduct further experiments to study the interaction of process model complexity with the effects of highlighting. The assumption for this work could be that highlighting benefits increase with an increase in model complexity. Beyond this, there are other types of secondary notation that we did not study in this research. Specifically, we aim to investigate to which degree the comprehension of a process model can be improved by a good layout. Prior work in the area of class diagrams suggest that comprehension would deteriorate with bad layout [65]. The challenge in this context will be, among others, to operationalize the notion of a good layout for process models. Furthermore, we want to explore the spectrum of visual parameters [46] that may be utilized to enhance process model comprehension. More specifically, many popular process modeling notations include a range of symbols with a fixed graphical form without any notable consideration of their cognitive discriminability. It would be interesting to work on a "make over" of such notations to improve their use; the developers of the YAWL modeling language [61], for example, have already expressed their willingness to cooperate in such an endeavor. Finally, we also have an interest in developing guidelines for process modelers with respect to the way they structure their models. The work on seven process modeling guidelines that we presented in [42] can be seen as a first step in that direction, which offers considerable potential for extension.

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