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AUTOMATED PLANNING OF PROCESS MODELS: THE CONSTRUCTION OF SIMPLE MERGES

Research

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Abstract

Business processes evolve dynamically with changing business demands. Because of these fast changes, traditional process improvement techniques have to be adapted and extended since they often require a high degree of manual work. To reduce this degree of manual work, the automated planning of process models is proposed. In this context, we present a novel approach for an automated construction of the control flow structure simple merge (XOR join). This accounts for a necessary step towards an automated planning of entire process models. Here we build upon a planning domain, which gives us a general and formal basis to apply our approach independently from a specific process modeling language. To analyze the feasibility of our method, we mathematically evaluate the approach in terms of key properties like termination and completeness. Moreover, we implement the approach in a process planning software and apply it to several real-world processes.

Keywords: Business Process Management, Process planning, Automated planning, Control Flow Structures.

1 Introduction

Nowadays, as markets change, customer needs shift and new competitors evolve dynamically, companies must frequently (re)design their business processes to adapt them. At the same time, business processes span not only across departments of a single company but also across interorganizational collaborations of multiple companies, which makes process models even more complex. For instance, according to Heinrich *et al.* (2015), a European bank has modeled and (re)designed over 2,000 processes in different departments and areas in a project. These process models, which are composed of actions and corresponding control flow structures, have been modeled using the ARIS toolset and documented to support upcoming improvements and adaptations of processes. To keep the process models up-to-date, frequent (re)designs due to, for instance, the aforementioned challenges of today's business world have been necessary. Moreover, the authors state that employees of the bank as well as executives of other branches such as insurance and engineering highlighted the fact that process flexibility has become more and more important within the last decade. The reasons most frequently mentioned for this increased demand for flexibility are the growing frequency and complexity of such process (re)design projects, which involve a significant degree of manual work (cf. also Hornung *et al.*, 2007).

To ensure the required flexibility, several research fields in Business Process Management (BPM) striving to support modelers and business analysts via automatic techniques are of increasing importance. The research fields process mining as well as process model verification and validation assist the analyst in the process analysis phase (e.g., Wetzstein *et al.*, 2007). Automated (web) service composition can be seen as part of the phases process implementation and process execution (Weber, 2007; Khan et al., 2010). In the process modeling phase, which we will focus on in this paper, the goal of the research strand automated process planning is to enable the automated construction of process models using planning algorithms (Heinrich et al., 2011; Heinrich et al., 2009; Henneberger et al., 2008; Hoffmann et al., 2012; Lautenbacher et al., 2009). Automated planning aims to increase the flexibility by definition (cf. van der Aalst, 2013) of the resulting process models and to (re)design process models - for processes that must be frequently (re)designed. The task of an automated construction of process models can be understood as a planning problem (Ghallab et al., 2004) with the objective to arrange actions and control flow structures in an appropriate order based on both, an initial state as well as a non-empty set of goal states. Here, using a nondeterministic planning domain, allowing an abstract representation of process models, independent from a specific process representation language, enables a widespread use. A fundamental challenge for the automated planning of process models is to construct control flow structures which represent the control flow of a process (Russell et al., 2006; van der Aalst et al., 2003). More precisely, in order to plan more complex process models, not only a sequence of actions but also control flow structures like exclusive choice, parallel split or simple merge have to be constructed in an automated manner (cf., e.g., Heinrich et al., 2015; Heinrich et al., 2009; Hoffmann et al., 2012).

The specific research goal of this paper is the automated construction of one of the most important control flow structures, namely simple merge. The simple merge serves as a join connector for two or more paths-segments (called branch) into one single subsequent branch (cf., e.g., Russell *et al.*, 2006; van der Aalst *et al.*, 2003) and thus reduces the size of process models. However, the construction of simple merges within an automated planning approach does not only focus on reducing the size of process models and thus – according to, for instance, Moreno-Montes de Oca *et al.* (2015), Mendling *et al.* (2010), Sánchez González *et al.* (2010), Cardoso (2007) – its complexity. More generally, we have to be able to construct minimal process models in our context by removing redundant and duplicate path-segments "as early as possible". Further, to increase the readability and understandability of process models especially for laymen, La Rosa *et al.* (2011) propose to use pattern-compounds (cf. also Gschwind *et al.*, 2008; Mendling *et al.*, 2010; Mendling *et al.*, 2007) as they represent well-formed and sound block-structured fragments of a process model. Simple merges as so called "join connectors" (Mendling *et al.*, 2010) therefore should only be constructed in accordance with the related "split connector" (i.e., the control flow structure exclusive choice). Following this, we aim to construct simple merges in accordance to existing exclusive choices.

The contributions of this paper are a formal definition of our planning domain and an algorithm for the automated construction of simple merges. In more detail:

• To follow the research field of automated process planning and thus to ensure a widespread use of our approach, we consider belief states (possibly infinite sets of world states that may exist before and after applying an action) as we address the planning of process models and thus abstract from individual process executions (cf. Ghallab *et al.*, 2004).

• When constructing simple merges in an automated manner, we have to construct *minimal* process models. Thus, we address nested simple merges in order to simplify process models by removing duplicate sequences of actions in several paths and construct simple merges "as early as possible".

• We further focus on constructing simple merges in *complete* in terms of merging all distinct paths of process models that can be merged.

• We have to consider block structures (cf. La Rosa *et al.*, 2011; Gschwind *et al.*, 2008; Mendling *et al.*, 2010; Mendling *et al.*, 2007) in order to increase the readability and understandability of process models by means of constructed simple merges.

In the following section, we discuss related work regarding our contributions ① to ③. Thereafter we present the formal foundation for our approach in Section 3 and the running example, we will use to illustrate our approach, in Section 4. Sections 5 and 6 elaborate the major design decisions and the

proposed method to construct simple merges. In Section 7 we evaluate our approach before we conclude with a discussion, limitations of our work and an outlook to future research.

2 Related Work

Our work contributes to the research fields in BPM striving to support modelers and business analysts via automatic techniques. Especially, it focusses on the (1) automated planning of process models and is related to (2) process model complexity, (3) process modeling recommender systems and (4) process mining. Thus, we want to summarize and delimit existing research in these fields to our approach.

Ad (1): The research strand of automated planning of process models envisions the construction of process models by means of semantically annotated process elements and a semantic reasoning (Heinrich and Schön, 2015; Heinrich *et al.*, 2008; Heinrich *et al.*, 2011; Henneberger *et al.*, 2008; Hoffmann *et al.*, 2012; Lautenbacher *et al.*, 2009). Especially in Heinrich *et al.* (2008) and Henneberger *et al.* (2008) the challenges and the general planning approach is discussed. In this context, Heinrich *et al.* (2009) and Heinrich *et al.* (2015) propose an algorithm that copes with the construction of exclusive choices based on the determination of conditions. Their approach creates conditions that enable the construction of different outgoing branches of an exclusive choice, based on co-domain of belief state variables. However, they do not cope with simple merges. In contrast, Hoffmann *et al.* (2012) and Hoffmann *et al.* (2009) discuss the need of constructing simple merges (XOR joins) within their planning. However they do not provide any kind of algorithm or implementation for this problem (we ensured this by requesting an implementation from the authors). Summing up, an approach to construct simple merges in an automated manner is not presented so far (cf. contributions **0** to **4**).

Ad (2): Following the idea of reducing the amount of manual work through automation, several works in the field of process model complexity address the appropriate construction of control flow structures as well. Process models need to be refactored based on rules regarding the envisioned structure of process models. Therefore, control flow structures need to be transformed and constructed respectively. Vanhatalo et al. (2008b), for example, present an approach for the automated completion of workflow graphs. Their method is based on a "well-behaved" graph with a single source (initial state) and a single sink (goal state). They aim at constructing simple merges only at the end of a process model (i.e., prior to the sink). Vanhatalo et al. (2009) and (2008a) introduce the concept of refined process structure trees and a method to represent workflow graphs in such a tree-based hierarchy of sub-workflows. They aim to identify these sub-workflows but not to consolidate equal sub-workflows (cf. 2). Polyvyanyy et al. (2011) extend this approach and present an algorithm to transform a "multi-terminal graph" (MTG), which means, a graph that has at least one source and at least one sink, to a "two-terminal graph" (TTG), which means, a graph that has exactly one source and exactly one sink. They aim to connect the existing, multiple sinks of a MTG to one common single sink of the resulting TTG, but not at consolidating equal subtrees (i.e., the representation of equal sequences of actions in different paths; cf. contributions 2 and **④**). Munoz-Gama *et al.* (2014) present an approach for the decomposition of process models. Their decomposition is based on so called "transition boundaries" or "place boundaries". That means that they identify subgraphs based on a single common action or belief state at the beginning of each subgraph. However, this is not a sufficient criterion for the construction of minimal process models and especially of nested simple merges (cf. 2). Such nested simple merges do not necessarily require a single common action or belief state at the beginning of a subgraph. Further, none of the approaches in research field (2) copes with a nondeterministic planning domain and a state space with possibly infinite sets of world states, which is essential when addressing the automated planning of process models (cf. $\mathbf{0}$).

Ad (3): The research strand of process modeling recommender systems focusses on issues like autocompletion of process models, finding (substructures of) process models in a repository suitable for a given problem definition or deciding where to start and stop modeling a process (cf., e.g., Fellmann *et al.*, 2015; Koschmider, 2007; Koschmider *et al.*, 2011) in order to reduce the manual modeling efforts. These works aim at suggestions on correct and fitting process fragments that can be used to complete existing process models. In detail, during the construction of process models, recommender systems propose fitting process fragments (saved in a process model repository) based on (semantic) similarity measures of the fragments and the given problem definition, represented by, for instance, incomplete constructed process models at hand. This promising work, however, does not aim on constructing simple merges in an automated manner (cf. especially $\mathbf{0}$ to $\mathbf{0}$).

Ad (4): Besides these approaches, process mining aims at the partially automated reconstruction and redesign of process models based on event logs. Process mining allows discovering, checking and enhancing process models including workflow patterns (cf., e.g., Gaaloul et al., 2005a) by means of event logs (cf., e.g., Accorsi et al., 2012; van der Aalst et al., 2012). As van der Aalst et al. (2012) explicate, process mining should support basic control flow structures. The authors stated that existing algorithms like the alpha algorithm (cf., e.g., van der Aalst et al., 2004; Gaaloul et al., 2005b; Gaaloul et al., 2005a) are able to construct simple merges. However, these algorithms follow a local perspective by examining pairwise relations between two actions. Thus, they do not aim to construct simple merges in complete (cf. 3) and may not provide minimal process models (cf. 2). Further, to the best of our knowledge, we found no approach to construct simple merges in an automated manner that considers block structures (cf. ④) for increasing the readability of the constructed process models. Moreover, current conversion algorithms (cf., e.g., Kalenkova et al., 2015), that translate Petri Nets into Process Models (here: BPMN), do not deal with the completeness (cf. **③**) of the constructed simple merges. Moreover, as process mining aims to reconstruct as-is process models based on event logs, it does not cope with the ex-ante construction of to-be process models as it is addressed in this paper. Further, the field of process mining usually does not cope with a nondeterministic planning domain and a state space with possibly infinite sets of world states. So, the approaches for the construction of workflow patterns (as stated in e.g., Gaaloul et al., 2005b; van der Aalst et al., 2010), used in process mining, do not aim to address contribution **O**. To sum up, to the best of our knowledge, there exists no approach that addresses all contributions $\mathbf{0}$ to $\mathbf{0}$.

3 Fundamentals

As stated above, the construction of simple merges is a nondeterministic planning problem with belief states because we abstract from an individual process execution (Ghallab *et al.*, 2004). Using a nondeterministic planning domain which is independent from a particular process representation language enables a widespread use and guarantees compatibility with many existing approaches in the literature (e.g., Bertoli *et al.*, 2001; Bertoli *et al.*, 2006). A nondeterministic planning domain consists of a nondeterministic belief state-transition system which is defined in terms of its belief states, its actions, and of a transition function that describes how (the application of) an action leads from one belief state to possibly many belief states (acc. Bertoli *et al.*, 2006; Ghallab *et al.*, 2004). More formally, a belief state-transition system and (non-)determinism in state space are defined as follows:

Definition 1 (*Nondeterministic state-transition system*). A nondeterministic belief state-transition system is a tuple $\Sigma = (BS, A, R)$, where

- BS is a finite set of belief states. A belief state $bs \in BS$ contains a set BST of belief state tuples. A belief state tuple p is a tuple of a belief state variable v(p) and a subset r(p) of its predefined domain dom(p), which we will write as p:=(v(p),r(p)).
- A is a finite set of actions. Each action a ∈A is a triple consisting of the action name and two sets, which we will write as a:=(name(a), precond(a), effects(a)). The set precond(a) ⊆BST are the preconditions of a and the set effects(a) ⊆BST are the effects of a.
- And $R: BS \times A \rightarrow 2^{BS}$ is the transition function. The transition function associates to each belief state $bs \in BS$ and to each action $a \in A$ the set $R(bs, a) \subseteq BS$ of next belief states.

According to this definition it is possible to represent possibly infinite sets of world states quite easily. Furthermore, it is a rather intuitive way – from a process modeling perspective – to represent certain preconditions and effects of actions.

Definition 2 ((*Non-)determinism in state space*). An action *a* is *applicable* in a belief state *bs* iff |R(bs, a)| > 0; it is *deterministic (nondeterministic)* in *bs* iff |R(bs, a)| = 1 (|R(bs, a)| > 1). If *a* is applicable in *bs*, then R(bs, a) is the set of belief states that can be reached from *bs* by performing *a*.

Based on both Definitions 1 and 2, a planning graph can be generated by means of different existing algorithms that progress from an initial belief state to goal belief states (see, e.g., Bertoli *et al.*, 2001; Bertoli *et al.*, 2006; Heinrich *et al.*, 2009; Heinrich *et al.*, 2011). In this paper, we primarily are extending these works by means of an approach to construct simple merges in an automated manner. With that said, we define our planning graph as follows:

Definition 3 (*planning graph*). A planning graph is an acyclic, bipartite, directed graph G=(N, E), with the set of nodes N and the set of edges E. Henceforth, the set of nodes N consists of two partitions: First, the set of flow nodes $Part_F$ (set F of flow nodes) which further contains two partitions, the set of action nodes $Part_A \subseteq Part_F$ (set A of actions) and the set of exclusive choice nodes $Part_{EC} \subseteq Part_F$ (set EC of exclusive choices), and second the set of belief state nodes $Part_{BS}$ (set BS of belief states). Each node $bs \in Part_{BS}$ is representing one distinct belief state in the planning graph. Each node $a \in Part_A$ is representing an action in the planning graph. Each node $ec \in Part_{EC}$ is representing an exclusive choice node in the planning graph. The planning graph starts with one initial belief state and ends with one to probably many goal belief states (with $Init \in BS$ and $Goal_j \in BS$).

When focusing on automated process planning, identical or very similar actions of a planning graph – as specified in Definition 3 – can be identified by using semantic concepts and automated reasoning (cf. e.g., Step 1, Heinrich *et al.*, 2015, p. 3). Such actions can then be identically (syntactically) labelled in the planning graph, which we will use in the following. However, our approach is not limited to the strand of automated process planning. In fact, for instance, within the research field of process mining, several works exist (see, e.g., Kindler *et al.*, 2006; van der Aalst *et al.*, 2010; Verbeek *et al.*, 2007) that use or construct graphs similar to planning graphs. Moreover, we envision to apply our approach to manually constructed process models by transferring them to the notions of a planning graph.

Given Definition 3, a planning graph consists of one to many paths. Here, a path is defined as follows:

Definition 4 (*path*). A path is sequence of nodes $n_p \in N$ starting with the initial belief state and ending in exactly one goal belief state.

Further, we define a branch as a subset of nodes regarding a particular path, starting with an *exclusive choice* node $ec \in Part_{EC}$:

Definition 5 (*branch*). A branch is a sequence of nodes $n_b \in N$ starting right after an exclusive choice node $ec \in Part_{EC}$ and ending in exactly one goal belief state. A branch therefore is a subset of nodes of a specific path.

4 Running example

We will use an excerpt of a real-world process taken from the order management of a European bank to illustrate our approach in the following. This excerpt of an order execution process model is represented by the planning graph (such a graph can be constructed with one of the approaches proposed by Bertoli *et al.*, 2006; Heinrich *et al.*, 2015; Heinrich *et al.*, 2009) shown in Figure 1. As illustrated, the order data must be entered and determined in a first step. After that, depending on the type of the security (conditions), a check must be stated and the order amount must be entered or calculated (in case of a stock order). Then, the plausibility of the order has to be proven and the order will get executed before the order is processed internally or externally and has to be assigned to a portfolio and documented. Finally, the order gets routed (note: the uppercase letters A-G are used to refer to the according XORs hereafter).



Figure 1. Planning graph of our running example

5 Design Process

In this section we will outline the major design decisions to address the contributions **0**-**4**. These major design decisions are as follows:

- 1) *Traverse backwards:* To construct simple merges, we traverse the planning graph backwards, starting from the goal belief states. As the planning graph ends with one to many goal belief states, it is necessary to start the traversal with these goal belief states to identify all potentially mergeable paths and thus to cope with **2** and **3**. The reason for traversing the planning graph backwards is that we are able to identify mergeable paths directly and do not need to traverse them completely from the initial state (like if we would use a forward traversal). Precisely, traversing backwards is effective because paths that can be combined by a simple merge need to *end* in both equal actions and equal control flow structures.
- 2) Mark flow nodes with tokens: To identify mergeable paths, we compare the flow nodes (partition $Part_F$) of the paths in a breadth-first manner, i.e., all flow nodes preceding the goal belief states are compared in the first iteration, all flow nodes preceding these in the second and so on. This approach, combined with 1), allows us to identify all mergeable paths directly (cf. 2 and 3), as they would be equal from a specific action in the path until the goal belief state. We use tokens to mark sets of equal flow nodes being part of different paths. For instance, given that the last flow node before the goal belief state is equal in three paths, we mark these flow nodes with the same token, otherwise with different ones. Continuing traversing backwards and annotating actions with tokens breadth-first allows us to recognize potentially mergeable paths even if they differ in subsequent iterations.
- 3) *Construct simple merges:* To assure that paths are merged only if they were split by an exclusive choice previously (cf. ④), we construct simple merges when we reach an exclusive choice in the backward traversal. Here, the annotated tokens are used to identify mergeable paths.

Addressing design decision 2), we have to handle the need of identifying equal sequences of flow nodes within different paths. Thus, we define so-called *equality groups*:

Definition 6 (equality group). An equality group $eg_t = (n_1, ..., n_m)$ is a tuple of flow nodes with the following properties:

- $n_i \in Part_F \text{ for all } i \in \{1, \dots, m\}$
- n_{i+1} succeeds n_i for all $i \in \{1, \dots, m-1\}$
- A token T_t denotes a flow node as member of the equality group eg_t

We denote the set of all equality groups by EG.

6 Method to Construct Simple Merges

In this section, we will elaborate and employ the above mentioned major design decisions to design a method that constructs simple merges and addresses the contributions $\mathbf{0}$ to $\mathbf{0}$.

6.1 Step 1: Merging one single exclusive choice

In the first step, we address to merge - as early as possible - two or more outgoing branches regarding a single exclusive choice. In this simple case, we conduct the following sub steps:

- (1) Check all paths, starting from their corresponding goal belief states. Mark equal flow nodes with the same *equality token*, starting with the last flow node before each goal belief state.
- (2) Continue traversing backwards, comparing the subsequent flow nodes of all paths. If the flow nodes of each considered equality group are still equal, simply add the same token to the flow nodes of these paths. If the flow nodes are different, add new tokens for each equality group of flow nodes. Consider that flow nodes could only be marked with the same additional token, if they are member of the same equality group so far, which means if their preceding (in the backward traversal) flow nodes are the same. We additionally add the tokens of previously marked flow nodes to each flow node for performance reasons with regard to later phases of our approach.
- (3) If an exclusive choice is reached while traversing the branches backwards, we need to check the first flow node of all outgoing branches. Those branches that are marked with the same *equality token* are mergeable as they contain an equal sequence of flow nodes. Thus, they have to be merged with a *simple merge* just before the beginning of this equal sequence, which we will recognize as all contained actions are marked only with equal tokens. Further, the belief states of the merged branches have be joined (regarding our running example, the set union of *SecurityType: fund, SecurityType: certificate* and *SecurityType: stock*) to get the accurate belief state regarding the single subsequent path after the simple merge. If the branches are not marked with equal tokens they will be merged only before the goal belief state. The reached exclusive choice itself is marked with a new token and all common tokens of the merged branches, too.

Note: If branches of an exclusive choice have different lengths, all branches, except the longest, stop the backward traversal at the exclusive choice. When the traversal of the longest branch reaches the exclusive choice, all outgoing branches are compared according to the upper description.

(4) Finally, we have to continue traversing backwards and marking all flow nodes with tokens. Further, the approach finally reaches the initial state and terminates.

To demonstrate this first step, we use the introduced order execution process model. For illustration purpose, we focus on the part of the process, which is framed in Figure 1. According to the example, both paths are marked with the token T_1 , as both paths end with the equal action "route order" (sub step (1)). Further, the actions "assign to portfolio and file documentation" and "receive portfolio assignment and filed documentation" differ and hence are additionally marked with different tokens (T_2 resp. T_3) according to sub step (2). Then, reaching the exclusive choice, the outgoing branches are identified as mergeable, as both contain the token T_1 . Thus, a simple merge is inserted before the action "route order", as this is the first flow node marked only with equal tokens in both branches (see rightmost graph in Figure 2). Further, all subsequent belief states (i.e., bs_3 and bs_4) have be joined.



Figure 2. Constructing a simple merge regarding the running example

6.2 Step 2: Merging multiple nested exclusive choices

When process models become more complex, exclusive choices could occur in branches of other exclusive choices etc. Thus, our approach must be able to cope with *nested* exclusive choices (e.g. exclusive choices E, F and G are nested in exclusive choice A; cf. Figure 1). To address this challenging problem, we need to consider the main components of an exclusive choice, the outgoing branches and their conditions, and define a *choice construct* as follows:

Definition 7 (*choice construct*). The choice construct *C* of an exclusive choice is defined as a set of c ($c \in C$) where *c* is defined for each outgoing branch of this exclusive choice. Moreover, *c* is defined as the tuple c:=(*Condition, Tokens*) consisting of the condition of the corresponding branch (or null if the branch has no conditions) and the tokens of the first action of the branch succeeding the exclusive choice.

Based on this definition we are able to cope with *multiple nested* exclusive choices. To enable the merging of several paths containing exclusive choices with equal choice constructs – and therefore with equal outgoing branches and conditions – we need to *extend* the above sub step (3) as follows:

(3') As defined above in sub step (3), when reaching an exclusive choice, merge the outgoing branches. Additionally, mark the exclusive choice with its choice construct. Compare the exclusive choice with every other exclusive choice based on their choice constructs similar to comparing actions and mark them with the same token, when two or more choice constructs are equal.

The general specification in the first step above in combination with the straightforward extensions of Definition 7 and sub step (3') allows us to cope with the problem of merging multiple *nested* exclusive choices in outgoing branches now. For further comparison the tokens of the outgoing branches of a nested exclusive choice are not required anymore and thus, when marking subsequent flow nodes, only the token of the exclusive choice is needed.

To illustrate these extensions, we consider the whole planning graph of our running example as seen in Figure 1, containing multiple exclusive choices (denoted by capital letters). Initially, the procedure is equal to the excerpt in Figure 2 until the exclusive choices B, C and D are reached. When reaching each of the exclusive choices E, F and G, both outgoing branches are marked with the equality tokens T_1 and thus are mergeable before the action "route order". Further, exclusive choice F is marked with its choice construct, precisely {(null, (T_2, T_1)), (null, (T_3, T_1))} (cf. sub step (3')). As exclusive choices E and G contain the same outgoing branches as F, they are marked with the same choice construct. According to sub step (3'), all of those three exclusive choices get marked with T_4 , as their choice constructs are equal.

When continuing the backward traversal, the exclusive choices B, C and D are reached and compared. They have to be marked with {({(Routability, false)}, null), ({(Routability, true)}, (T_4, T_1))} and their

outgoing branches can be merged. As there is only one outgoing branch that leads to the goal¹, no further merge is needed. Thereafter (cf. sub step (4)), the outgoing branches of exclusive choice A are checked. As they all contain the equal token T_5 (cf. the equal exclusive choices B, C and D) they will be merged before the action "prove plausibility" resulting in the graph shown in Figure 4.

6.3 Step 3: Merging exclusive choices within parallelization compounds

Regarding Mendling *et al.* (2010), process models should be "as structured as possible" (i.e., "every split connector matches a respective join connector of the same type"), which is related to contribution \bullet . So far, the proposed approach is not able to provide this in case an exclusive choice is created within a parallelization compound (i.e., path segments surrounded by a parallel split node and a synchronization node). To solve this issue, the Definitions 3 to 5 must be extended to allow the representation of planning graphs containing parallelization compounds:

Definition 3' (*planning graph*). A planning graph is an acyclic, bipartite, directed graph G=(N, E), with the set of nodes N and the set of edges E. Henceforth, the set of nodes N consists of two partitions: First, the set of flow nodes $Part_F$ (set F of flow nodes) which further contains four partitions, the set of action nodes $Part_A \subseteq Part_F$ (set A of actions), the set of exclusive choice nodes $Part_{EC} \subseteq Part_F$ (set EC of exclusive choices), the set of parallel split nodes $Part_{PS} \subseteq Part_F$ (set PS of parallel splits) and the set of synchronization nodes $Part_{S} \subseteq Part_F$ (set S of synchronizations), and second the set of belief state nodes $Part_{BS}$ (set BS of belief states). Each node $bs \in Part_{BS}$ is representing one distinct belief state in the planning graph. Each node $a \in Part_A$ is representing an action in the planning graph, each node $ec \in Part_{EC}$ is representing an exclusive choice node in the planning graph, each node $p \in Part_{PS}$ is representing a parallel split node in the planning graph and each node $s \in Part_S$ is representing a synchronization node in the planning graph. The planning graph starts with one initial belief state and ends with one to probably many goal belief states (with $Init \in BS$ and $Goal_j \in BS$).

Definition 4' (*path*). A path is sequence of nodes $n_p \in N$ either 1) starting with the initial belief state and ending in exactly one goal belief state or 2) starting with a parallel split node $p \in Part_{PS}$ and ending in the corresponding synchronization node $s \in Part_S$.

Definition 5' (*branch*). A branch is a sequence of nodes $n_b \in N$ starting right after an exclusive choice node $ec \in Part_{EC}$ and ending in exactly one goal belief state or a synchronization node $s \in Part_S$. A branch therefore is a subset of nodes of a specific path (see Definition 4').

Now, we are able to represent process models containing parallelization compounds by means of our planning domain. The upper part of Figure 3 shows an extension of our running example illustrating this. To enable the automated construction of simple merges within parallelization compounds we carefully extend the previously presented sub steps (1), (3) resp. (3') and (4) as follows:

- (3") When reaching a synchronization node, invoke the overall method (i.e., sub steps (1_{para}), (2), (3), (3'), (4_{para})) for all paths between the parallel split node and the synchronization node.
- (1_{para}) Check all paths, starting from the final synchronization node. Mark equal flow nodes with the same *equality token*, starting with the last flow node before the synchronization node.
- (4_{para}) Continue to traverse backwards and mark all flow nodes with tokens. Further, when finally reaching the initial parallel split node, return to the enclosing iteration.

We follow the above presented idea, used for merging nested exclusive choices, to allow merging branches that contain *nested* parallelization compounds and define a so called *parallel construct* based on the contained actions:

¹ The other outgoing branch leads to a so called flow final node, which terminates the process and is not needed to be merged.

Definition 8 (*parallel construct*). A parallel construct *P* of a parallel split is defined as a set of T_t ($Tt \in P$) where T_t is denoted for each outgoing branch of this parallel split. Moreover, T_t is defined as the token of the first flow node of the branch succeeding the parallel split.

Further, when merging a nested parallelization compound, we compare it with every other parallelization compound in the currently analyzed equality group based on their parallel constructs (cf. sub step (2)) and mark them with the same token, when two or more parallel constructs are equal.

Regarding our running example (Figure 3), we traverse the parallelization compound backwards, starting with the synchronization node as stated in (1_{para}) . Thereupon, "enter quantity" could be identified as equal in the two branches of the exclusive choice in sub step (2). When continuing the traversal and finally reaching the exclusive choice, these two branches will be merged as seen in the lower area of Figure 3 regarding (3). Regarding the previously defined sub steps (1) to (4), the parallel split will be marked with the parallel construct $\{T_2, T_4\}$ when finishing the traversal of the parallelization compound (cf. (4_{para})), as "determine real-time market value" gets marked with T_2 and "determine budget" gets marked with T_4 . To sum up, we are now able to create minimal and block-structured (cf., e.g., La Rosa *et al.*, 2011; Mendling *et al.*, 2010) process models by constructing simple merges in complete.



Figure 3. Unmerged and merged exclusive choice within a parallelization compound

7 Evaluation

In this section, we sketch the formal evaluation of our approach by mathematically proving that it provides minimal process models (i.e., simple merges are constructed "as early as possible"; cf. O), constructs simple merges if possible (i.e., completeness; cf. O) and terminates. We further briefly sketch its computational complexity and evaluate the results of our approach with respect to the construction of block structures (cf. O). Afterwards we evaluate the feasibility of the approach by means of a prototypical implementation and applying it to several real-world processes.

7.1 Formal evaluation of the approach

For the formal evaluation of our approach, we need to ensure that it terminates, identifies all mergeable paths (completeness), does not construct incorrect simple merges (correctness) and constructs simple merges as early as possible (i.e., is minimal). It is proven, that the approach meets all these criteria and its computational complexity is $O(n^5)$ in the number of goal belief states or sequential flow nodes of the longest path of the planning graph. This means, the algorithm is computationally efficient (cf., Arora and Barak, 2009; Cobham, 1965). It is further proven that for each exclusive choice, exactly one simple

merge is created (cf. O) so that the results of the approach are syntactically correct and fulfill the criteria of soundness and s-coverability. For the proof sketches see Appendices B and C².

7.2 Operational evaluation of the results

To assess the feasibility and applicability of our approach, the following questions are evaluated: (E1) Can our approach be instantiated in terms of a prototypical software implementation? (E2) Can it be applied in a practical setting and what is the output resulting from its application?



Figure 4. Screenshot of the constructed process model by means of our prototype

We integrated our approach in a web-based process planning tool (cf. E1; a demo version could be accessed at <u>http://www-sempa.uni-regensburg.de/</u>). The web application guides the user while populating the set of actions by providing descriptions of preconditions and effects and specifying the initial state and goal states. To test the implementation, persons other than the programmers analyzed the source code and several extreme value tests and unit tests have been performed. The implementation did not show any errors at the end of the test phase.

By means of the software implementation, we applied our approach to several real-world processes of a European bank, European insurance companies and an educational institution (cf. E2). Our running example is a part of one of these processes and addresses the order management of the bank (cf. Figures 1 and 5). To be able to apply our algorithm, the actions of former process models, used in the area of security order management had to be extracted and afterwards imported in our planning tool. About 200 actions including their preconditions and effects could be imported via an XML interface of ARIS, the bank's process modeling tool. We then reviewed them to validate, for instance, that their preconditions and effects were accurate noted. Finally, we specified the initial state and the intended goal states with the help of the employees of the bank's responsible department and planned the feasible process models using our planning tool. Hereby, two simple merges are constructed. The simple merge node that is firstly constructed merges the branches after "receive portfolio assignment and filed documentation"

² A version of this paper, containing all Appendices could be accessed via http://epub.uni-regensburg.de/33576/

and "assign to portfolio and file documentation". Its construction is straightforward as no nested exclusive choices need to be created. In the next step, the outgoing branches of the exclusive choices B, C and D are analyzed. As here only one branch leads to the goal and the other branch leads to a flow final node, no further simple merge needs to be created. As the previously merged exclusive choice occurs in this branch again, it is needed to consider the extensions for merging nested exclusive choices (cf. Section 5.2). In the last step, a simple merge node before "prove plausibility" merges the three different branches depending on the security type. Here, the extensions for nested exclusive choices (cf. Sec-5.2) have to be considered again. In conclusion, only one action ("enter order amount") appears twice in the process model due to respecting pattern compounds (cf. contribution **④**).

Process number	Context	Num. of ac- tions / states in the initial search graph	Num. of constructed simple merges	Num. of ac- tions in- cluded by the simple merge	Num. of actions and control flow struc- tures merged by the simple merge	Num. of merged paths	Run time in sec.
1	Project Mgmt.	17/15	1	4	1/0	3	< 0.001
2	Project Mgmt.	25/18	1	1	7/2	2	< 0.001
3	Project Mgmt.	26/22	3	8	8/1	4	0.002
4	Project Mgmt.	38/25	2	6	36/3	4	< 0.001
5	Insurance Mgmt.	43/38	6	29	19/7	27	0.016
6	Insurance Mgmt.	54/44	8	33	18/8	3	0.006
7	Loan Mgmt.	40/31	3	25	12/3	3	0.003
8	Loan Mgmt.	57/43	4	14	11/4	20	0.013
9	Loan Mgmt.	122/69	3	54	4/0	0	0.024
10	Private Banking	278/189	25	82	69/16	6772	5.405
11	Human Res.	83/75	10	76	3/0	4	0.016

Table 1.Application of our approach in further real-use situations

As stated above, we applied the approach to further processes in different contexts of different firms. Table 1 shows the results of these applications (executed on an Intel Core i7-2600 3.40 GHz, Windows 7 64 Bit, Kernel Version 7601.22616, Java 8). The eleven analyzed processes of different application contexts include up to 278 actions and 189 states in the initial graph and are therefore of a small to a large size. The largest process model No. 10, for instance, contains actions conducted by several departments of the European bank and external service providers. Other processes are run by an insurance company, a mechanical engineering company (the context "Project management") and a university (the context "Human resources"). All process models include simple merges and for many process models nested control flow structures were created that merge a significant number of actions and states. This illustrates that nested simple merges are frequently used and relevant control flow structures. In all situations, our approach was fully applicable and generated correct and complete solutions. Thus the practical applicability of the approach is supported. The run time to construct simple merges varies from 0.001 up to 5.405 sec. and is thus very small.

Regarding economic aspects, Krause *et al.* (2013) present a quantitative evaluation, analyzing 18 process modeling projects from a financial service provider. Here, automated planning generates higher initial setup costs than manual process modeling, especially for analyzing and annotating actions. In contrast, the ongoing modeling costs are (as expected) much lower because of the support by the automated planning approach. Moreover, Krause *et al.* (2013) show that the use of automated planning of process models increases the contribution margin by about 20% which should cover its necessary higher initial investments. Automated planning should likely be even more valuable over a long term as Krause *et al.* (2013) considered only a short period of time. Alongside with this findings, applying the presented approach allows reducing the manual efforts when constructing process models and thus reduces the variable costs within the planning process. Hence it is supported that our approach is even more valuable for process models that need to be redesigned frequently as the initial costs can be amortized by savings

of parts of the variable costs that occur with each redesign (cf. also Heinrich *et al.*, 2015). Furthermore, the complexity of the process model could be decreased by reducing the amount of nodes within the process model, which then may lead to less errors during the execution of the process (cf. La Rosa *et al.*, 2011; Laue and Mendling, 2010; van der Aalst *et al.*, 2008).

8 Discussion and Conclusion

We propose a novel approach to construct the control flow structure simple merge in an automated manner and thus contribute to the research strand of automated process planning. Further, this work aligns to several research fields in BPM striving to support modelers and business analysts via automatic techniques. To abstract from individual process executions and to ensure a widespread use of our approach, we consider belief states (cf. ①). We construct minimal (cf. ②) and complete (cf. ③) process models. Within this paper we additionally considered the construction of pattern compounds as proposed by e.g. La Rosa *et al.* (2011) in order to increase readability and understandability of the process models (cf. ④). Our approach and the planning domain are formally noted and can therefore be well-defined and evaluated by means of mathematical proofs. This guarantees that key properties and envisioned contributions are met. Further, we discussed its applicability, feasibility and the results from the practical application by applying our approach (implemented in a process planning tool) to several real-world processes. In this context, we have tested that the construction of simple merges contributes to the automated planning of entire process models and thereby to reduce the amount of manual efforts within process (re-)design.

However, our research has some limitations that need to be addressed in the future. Constructing block structures (cf. O) may imply redundancies in the resulting process model that will not be merged in some cases (cf. action "enter order amount" in our running example). In some cases this might not be favorable, for instance, if the resulting process models are used only by domain experts in process modeling. In future research, this issue has to be addressed. To enable this, choice constructs of nested exclusive choices have to be compared in depth instead of only using their token to identify mergeability.

To complete the automated planning of entire process models, further (advanced) control flow structures should be constructed. Moreover, the work of Krause *et al.* (2013) should be followed-up to ensure a valuable usage of automated process planning in future real-world cases. For instance, it should be evaluated whether automated process planning makes it easier for laymen to construct correct and feasible process models. Further, it should be evaluated how the presented approach could be applied in other research strands such as process mining. As process mining approaches usually employ event logs to derive process descriptions (e.g., process graphs), we expect our approach to be beneficial especially regarding contributions **2** and **3** in this research strand, too. However, this idea needs to be evaluated in future research.

Further, it should be evaluated how process models modeled in a manual manner could be enriched to enable transferring them to planning graphs. Additionally, combined with assessing the semantic similarity of actions, our approach seems promising for supporting modelers as planning approaches (cf., e.g., Bertoli *et al.*, 2006; Heinrich *et al.*, 2008; Heinrich *et al.*, 2011) are already based on semantic annotations. For assessing the similarity of actions and subgraphs, works in the research fields of process management (cf., e.g., Ehrig *et al.*, 2007; Minor *et al.*, 2007; Montani *et al.*, 2015) and web service composition can be applied as especially the latter ones use input and output parameters as we do (cf., e.g., Dong *et al.*, 2004). Such works should be useable in the context of automated planning of process models as well. However, actions that are similar but not equal may not be merged in an automated manner but it might be possible to suggest modelers which actions may be merged after a modification. Such an extension of our approach provides a basis for promising advancements in the future.

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