Decision Support Systems 78 (2015) 1–14

Contents lists available at ScienceDirect

Decision Support Systems

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

Automated planning of process models: Design of a novel approach to construct exclusive choices

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ARTICLE INFO

Article history:
Received 28 August 2014
Received in revised form 2 July 2015
Accepted 14 July 2015
Available online 22 July 2015

Keywords:
Process model
Automated planning
Exclusive choice
Algorithm
Design science research

ABSTRACT

In times of dynamically changing markets, companies are forced to (re)design their processes quickly and frequently, which typically implies a significant degree of time-consuming and cost-intensive manual work. To alleviate this drawback, we envision the automated planning of process models. More precisely, we propose a novel algorithm for an automated construction of the control flow pattern 'exclusive choice', which constitutes an essential step toward an automated planning of process models. The algorithm is built upon an abstract representation language that provides a general and formal basis and serves as the vocabulary to define the planning problem. As part of our evaluation, we find that, based on a given planning problem, our algorithm is not subject to potential modeling failures. We further implement the approach in process planning software and analyze not only its feasibility and applicability by means of several real-world processes from different application contexts and companies but also its practical utility based on the criteria flexibility by definition, modeling costs, and modeling time.

1. Introduction

In times of dynamically changing markets, companies must frequently (re)design their business processes to adapt them to new market conditions such as shifting customer needs and new offers of emerging competitors. At the same time, companies are increasingly embedded in interorganizational, process-based collaborations, a fact that makes process (re)designs all the more complex. For instance, we are involved in an extensive project including several process (re)designs with a European bank in which over 600 core business processes and 1500 support processes are modeled in different departments and areas. These process models, which are composed of actions and corresponding control flows [33], are modeled using the ARIS toolset and documented in a company-wide process repository to support the standardization of processes and to have a common base for process (re)design projects. To keep the process models updated, it is necessary to frequently (re)design process models due to changing market conditions such as new products, new distribution channels, and new regulatory obligations. Several interviews with IT and business executives of the bank highlighted the fact that today's process (re)design projects are more cost-intensive and time-consuming than such projects were 10 years ago due to their higher complexity. This change also became evident in interviews with executives of other branches such as insurance and engineering. The most frequently mentioned reasons for increasing costs and duration are the growing frequency and complexity of such process (re)design projects, which involve a significant degree of manual work (cf. also [32]).

The research strand of Semantic Business Process Management (SBPM) aims to alleviate this drawback by using semantic technologies to enable a higher level of automation when designing, processing, executing, and analyzing processes and process models [26]. Wetzstein et al. [58] structure the scope of SBPM in their SBPM lifecycle and differentiate four phases: SBP modeling, SBP implementation, SBP execution, and SBP analysis. In our research, we aim to contribute to SBP modeling. The objectives in this phase are the semantic annotation, the design, and the adaptation of process models in an automated manner and their evaluation to ensure feasibility and (practical) utility [58].

Focusing on the SBP modeling phase, we envision the automated planning of process models. We aim to develop a planning approach that automatically arranges semantically annotated actions in a control flow leading from an initial state to desired goal states. When applying such an approach, the (re)design of process models is no longer performed manually but by an algorithm that uses semantic concepts and automated reasoning. With this research, we aim to increase the flexibility by definition (cf. [49]) of the resulting process models and to (re)design process models - for processes that must be frequently (re)designed – to be more cost-efficient and less time-consuming

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http://dx.doi.org/10.1016/j.dss.2015.07.005
0167-9236/

compared with manual process modeling. For automated process planning, it is insufficient to construct sequences of actions because entire process models include control flow patterns [43]. The specific research goal of this paper is the automated construction of one of the most important control flow patterns, namely exclusive choice.

Therefore, we initially define an abstract representation language to express the preconditions (comprising everything an action requires to be applied, including input parameters) and effects (how an action affects the state of the world, including output parameters) of actions and belief states (possibly infinite sets of world states that may exist before and after applying an action). Using this abstract representation language, we define our planning problem and, most importantly, design a novel algorithm for the automated construction of exclusive choices. As part of the evaluation, we find that, based on a given planning problem, our algorithm is not subject to potential modeling failures. We further implement the approach in SBPM process planning software and analyze not only its feasibility and applicability by means of several real-world processes but also its practical utility based on the criteria flexibility by definition, modeling costs, and modeling time.

The research presented in this paper is based on the Design Science Research paradigm [18,27]. In the Introduction section, we motivated the research problem — the automated construction of exclusive choices. In Section 2, we discuss contributions addressing related research problems (prescriptive knowledge) and elaborate the research gap. In Section 3, we present a general approach for an automated planning of process models to inform our research problem (descriptive knowledge). In Section 4, we introduce a running example to illustrate the basic idea of our approach as well as each design step in the remainder of the paper. In Section 5, we present our approach for an automated construction of exclusive choices. Section 6 is dedicated to the evaluation of our approach. In Section 7, we discuss limitations and directions for future research before we conclude with a summary of our key findings in Section 8.

2. Related literature

Works addressing research problems that are related to the automated construction of exclusive choices are found in the research fields of Automated Planning and SBPM. Beginning with the literature in Automated Planning, the planning problem addressed in this paper can be characterized as a nondeterministic planning problem with initial state uncertainty. Algorithms that can cope with nondeterminism and initial state uncertainty [4,8,28] are called conditional planning approaches. When constructing exclusive choices in process models, an approach must cope with large data types (e.g., double) and possibly infinite sets of world states. However, according to Geffner [15], a key problem in large state spaces – resulting from large data types and possibly infinite sets of world states – is representing belief states and enabling mapping of one belief state onto another. In this context, Bertoli et al. [4] propose the use of Binary Decision Diagrams. Another possibility is the implicit representation of a belief state by an initial state in combination with a sequence of actions that leads to the belief state to be represented [29]. Further planners explicitly enumerate all world states that may occur after applying an action [7]. However, in the context of planning process models and constructing exclusive choices, it is essential to cope with large data types accompanied by infinite sets of world states. This issue has not thus far been addressed by existing approaches. Moreover, existing conditional planning approaches operate with so-called observations, which are points in the plan at which it is necessary to validate some logical expression to define how to proceed. However, these observations are encoded separately in the form of observation variables and observation actions making them both part of the given planning domain. Here, the observations in the domain description constitute the only points in the plan in which the control flow might branch (e.g., to construct exclusive choices). Thus, it is possible to consider exclusive choices using existing conditional planners [8,28], but they must be "hard-coded" in the domain (e.g., by sensing actions) and are additionally restricted to Boolean variables. However, in the context of planning process models, the points in the plan at which exclusive choices appear are not given; rather the corresponding conditions for which the control flow branches must be planned considering large data types. This challenge has so far also not yet been addressed by existing planning approaches.

In addition to the literature on Automated Planning, we discuss related approaches in the field of SBPM structured according to the phases of the SBPM lifecycle by Wetzstein et al. [58]:

SBP analysis: This phase comprises process mining and the validation of existing process models. The goal of process mining algorithms is to deduce process models from event logs representing recorded information about (many) former executions of the considered process [50,52]. The deduced process models can then be compared with the deployed process models and thus be used for conformance checking and optimization purposes [53]. Existing process mining algorithms are able to identify control flow patterns based on dependency relationships observed in the event logs [3,14,17,50,51,56,57]. However, because these approaches focus on dependencies among actions, they do not aim at deriving the conditions of exclusive choices, which is an indispensable step toward our goal of planning exclusive choices in process models. Moreover, to derive the conditions of exclusive choices in the case of large data types, the event log would have to contain information about a possibly infinite number of process executions, which is rather unrealistic. Another major difference between process mining and the automated planning of process models refers to the fact that process mining aims at *re*constructing models for *as-is* processes to capture the processes as they are actually being executed [57]. In contrast, the automated planning of process models focuses on the construction of *to-be* process models for a given planning problem. Further related work in the SBP analysis phase aims at examining the consistency of existing process models [13,34,55]. These approaches validate whether the actions (within a process model) are consistent both among themselves and with respect to the control flow patterns used. Thus, they check whether exclusive choices are consistently constructed in given process models but do not focus on elaborating a planning domain or an algorithm to construct exclusive choices.

SBP implementation and execution: Within these phases, (web) services that are required to execute processes are composed in an automated manner. For that purpose, multiple service composition approaches were developed in recent years that are motivated by a problem definition related to planning process models [1,5,6,11,30,36–38,40,42,45,46,48,54,59] (for a current overview of research on web service composition see e.g., [44]). However, few of them consider conditions that are required to construct exclusive choices. For instance, Meyer and Weske [38] propose to extend an enforced Hill–Climbing algorithm to support the construction of alternative control flows. They add an or-split to the service composition "if subsequent services cannot be invoked in all states". However, they do not consider belief states able to consider possibly infinite sets of world states. Bertoli et al. [6] (and other authors such as Wu et al. [59]) propose a planning framework to create a composite service that can handle services specified and implemented using industrial standard languages for business process execution. However, they do not focus on planning conditions for exclusive choices but on identifying one feasible service composition based on a search tree. Wang et al. [54] aim at integrating conditional branch structures in automated web service composition to represent users' diverse and personalized needs in combination with dynamic environmental changes. They propose algorithms that are based on formalized user preferences (e.g., $P = AccountBalance \geq Payment? - PayInFull: PayByInstalments$; i.e., the user will pay in full, if (s)he has sufficient money; otherwise, (s)he will pay by installments). These