Constraint-based scheduling and planing in medical facilities with BPMN

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Abstract. This paper presents an approach to transform BPMN-models of medical treatment processes into CSPs for resource planning and scheduling. The constraint-models created by the transformation can then serve as input to existing constraint-based planning systems already in use in health care. Models for these existing systems can rarely be created or adjusted by domain experts like physicians or hospital administrators. The transformation aims to help them manage and adjust their processes and planning systems without the assistance of IT-experts when requirements or regulations change.

1 Motivation

Cost pressure in public health care services has been increasing constantly in recent years. With improved living standards and medical progress granting a longer life expectancy, the number of patients whose old age is accompanied by multiple chronic diseases has also increased. These senior citizens can enjoy a high quality of life, but to do so, they need lifelong treatment. With the introduction of *Diagnostic Related Groups* (DRGs) in 2004 there also was a paradigm shift in hospital billing [1]. Prior to 2004, medical facilities where paid according to each patient's duration of stay. With DRGs they now can bill only one flat charge based on the patient's diagnosis. These and further developments in health care led to the need for more organizational and financial efficiency, which nevertheless must be achieved without reducing the quality of treatments or patients safety.

2 Planning and scheduling with BPMN

One approach to achieve this raise in efficiency was the introduction of methodologies from the area of *Business Process Management* (BPM) to public health care. Thus, formal descriptions of treatment processes in workflow-languages like BPMN became available. Also, tools and methods from Constraint-Programming have already been in use in clinic environments for decades, i.e. for staff rostering, surgery planning or dialysis management [2].

The constraint-solvers that are foundation of these planning systems need properly specified constraint-problems, which usually are created and maintained by IT-specialists. Medical staff like physicians or hospital administrators are rarely able to comprehend these models and can not adapt them when requirements or regulations change. But in BPM exist graphical notations to describe treatment processes as workflows. The BPMN-language [3] offers a quickly comprehensible notation that can be understood even by non-IT-experts.

The aim of this work is an automatic transformation from BPMN-treatment models to Constraint Satisfaction Problems (CSP) [4] for time- and resource planning. It aims to enable domain experts to adapt their medical processes on their own for their existing planning systems, thus complementing the planning systems in a useful way. The generated CSPs can then be solved by a constraint-solver to generate plans that allocate the process activities to the available medical staff and resources in an optimal way, thus helping in the coordination and daily operation of the medical facilities. Schedules can be optimized for different goals like minimal waiting times or maximal throughput of patients even with a reduced staff during holiday times.

2.1 The BPMN-language

The *Business Process Model and Notation* (BPMN) is a graphical modelling language for business processes [3]. A *process* is a set of predefined activities that are performed either automatically or manually in order to achieve one or more business goals [5]. A process is an instance of a process model. It has a state that may change over time and it may also communicate with other running instances of the same or other process models.

The base elements of a BPMN process model are depicted in Figure 1. Activities represent units of work that are carried out in the process. Gateways define the control flow of the process, so that activities might be executed only under certain conditions or e.g. in parallel or alternatively. Events like time-outs, errors or messages may occure while a process is running. Every process has a start event and at least one end event. The aforementioned elements are flow objects, which are connected by sequence flows if they belong to the same process or message flows, when they originate from external processes. Pools and lanes are used to group activities and assign them to participants who take a role in the process.

For each gateway type there exists a split and a join version. Both have the same symbol. A split gateway has one incoming and at least two outgoing sequence flows. Join gateways are the target of two or more sequence flows and have one outgoing sequence flow. The exclusive gateway selects exactly one out of several outgoing branches, which is then executed. Branches that are enclosed by parallel gateway objects are executed concurrently and are synchronized at the join element. The execution of the process instance is continued behind the parallel join after the last branch is terminated. An inclusive split selects at least one or more of its outgoing branches that are then executed in parallel.

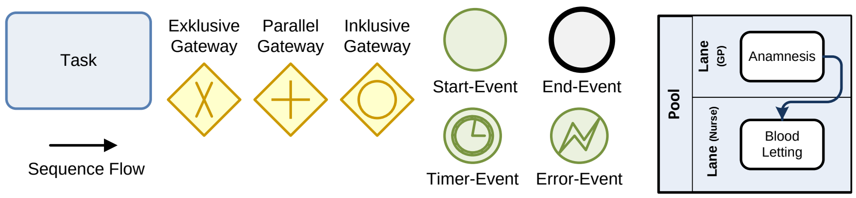

Fig. 1. Base elements of the BPMN-language

2.2 Transformation

In the current state of work basic BPMN-models can be transformend automatically into CSPs with finite domain constraints. The target platform is the JAVA-based CHOCO solver (version 2.1.5), which then generates and optimizes the plans.

For each activity A in a process instance three integer variables A_{start}, $A_{duration}$ and $A_{end} \in \mathbb{N}$ are created that model start- and ending time as well as the duration of the activity in the CSP together with the constraint $(A_{start} + A_{duration} = A_{end})$. For activities that may only be executed conditionally an additional variable $A_{active} \in \{0, 1\}$ is created and reified with the constraint $(A_{active} = 1) \Leftrightarrow (A_{start} = -1 \wedge A_{duration} = 0)$.

For gateways and sequence flows simple precedence constraints are generated that take into account the predecessor and successor elements. That way, also non well-formed models are supported, which do not always contain a closing join-gateway for every split-gateway. An additional generation of global constraints that takes into account the block structure of the model for enhanced filtering and pruning of non-solutions is under development.

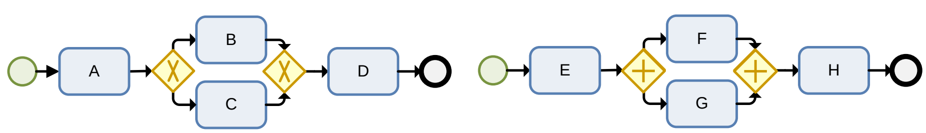

Fig. 2. Example processes with exclusive and parallel gateways

Sequence flows between two activities A and B are represented by simple precedence constraints $(B_{start} \geq A_{end})$. By convention, a gateway that selects and activates outgoing branches is always preceded by an activity that results in the decision which outgoing branches need to be activated by the gateway [6].

Gateways are represented by corresponding constraints. Figure 2 depicts two simple, exemplary process models with exclusive (1) and parallel gateways (2), for which the following constraints are generated:

(1) $((B_{start} \geq A_{end} \wedge D_{start} \geq B_{end} \wedge C_{active} = 0) \oplus$
$(C_{start} \geq A_{end} \wedge D_{start} \geq C_{end} \wedge B_{active} = 0))$

(2) $(F_{start} \geq E_{end}) \wedge (G_{start} \geq E_{end}) \wedge (H_{start} \geq max(F_{end}, G_{end}))$

2.3 Resource Abstraction with Feature Models

As mentioned before, medical personal is rarely able to write or even adapt constraint notation. Therefore, an abstraction layer was introduced that hides the complex resource descriptions for the constraint-solver behind a facade of configurable medical domain objects. This approach aims to enable domain experts to plan with resource objects that they understand (exam rooms, stationary or mobile medical devices, etc.). These resource descriptions and their facades can then be authored by IT-experts and provided to domain experts in a toolbox, who then can instantiate and configure them according to their environment.

The descriptions are based on *feature models* with numerical attributes. They stem from the area of *Software Product Lines* and are used to model variability in configurable software products [7]. A feature-model describes all possible products of a product line by a combination of product features, which can be interrelated by additional constraints.

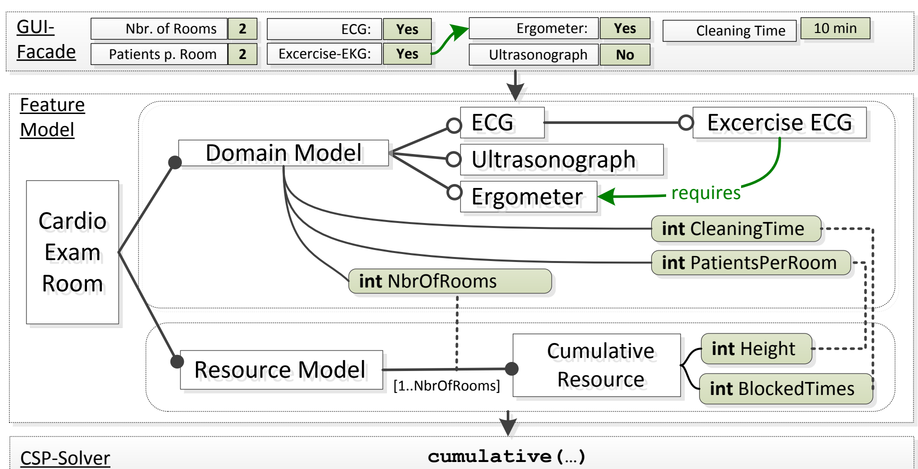

Fig. 3. Resource abstraction with feature models

Figure 3 depicts the concept on an exemplary cardiological examination room. The room resource can be configured through a simple GUI that represents the domain model part of underlying feature-model. The elements of the domain model part are linked to features and attributes in the resource model part, which in turn represent resource definitions like cumulative resources and tasks.

3 Related Work

Gonzales-Ferrer et. al. present a transformation from BPMN-process models into *Hierarchical Task Networks* (HTN) [8]. They support a subset of BPMN. Compared to constraint-based scheduling an HTN-planner uses a decomposition method to generate a plan. The plan consists of an ordered list of steps to reach a certain goal, but does not include any time information.

BPMN models have a strong connection to Petri-nets [9]. Many BPMN tools use Petri-net simulation and analysis techniques. [10] describes an approach to use Petri-nets with time to solve scheduling problems by generating a petri-net with special sub-structured that represend scheduling elements like tasks, resources or precedence relations.

An extension of BPMN that allows to explicitly model temporal constraints and other scheduling properties directly in the BPMN diagram is presented in [11].

4 Future Work

Loops BPMN models may contain loops, for example when a procedure has to be performed multiple times until the desired result is achieved. In order to provide realistic plans these loops need to be supported by the transformation. Since the target is a CSP solver, which can only generate finite plans, compromise approaches like limited loop-unrolling need to be evaluated, where only a limited set of iterations are planned in advance. In case more iterations are necessary, a re-planning can be performed. The process model could also be annotated with additional information from domain experts or history data from a process monitoring system with the minimum, average and maximum number of iterations. Since the transformation is targeting human-centric health care processes, this approach appears to be viable since medical procedures like x-rays can only performed a maximal number of times on a patient.

Optimized search heuristics The heuristics for variable and value selection, that control the constraint-solver when exploring the search space, significantly influence the speed in which a solution is found. As this is crucial especially in time critical and interactive scenarios, it will be investigated to what extent optimized search heuristics can be inferred from the BPMN-model and how they perform compared to strategies automatically chosen by the constraint solver.

Case study In order to evaluate the transformation approach in real world environments a case study will be conducted. A scenario in an emergency ward has already been surveyed, but found not to be an ideal site of operation for an interactive planning system. Doctors and nurses have to deal with massive multitasking and very diverse and above all time critial treatments and can not be expected to follow suggestions generated by an automated system above their own intuitions and experience.

Instead, scenarios in specialized facilities like ophthalmic clinics or radiology practices seem to be very promising, since here a number of treatment steps are performed by nurses operating medical devices, which could benefit from optimized planning and result in lower patient waiting times. Also, time is not as critical a factor as in an emergency ward and patients will mostly not arrive unexpectedly but will usually have appointments. Furthermore, the procedures performed in these facilities are not too diverse and have a better chance to be described as business processes and processes by an automated planning system.

5 Summary

This paper presents an automatic transformation from medical BPMN-treatment models intro constraint problems for time and resource allocation to complement existing automatic planning systems used in health care. It aims to allow domain experts like physicians or hospital administrators to adapt their processes and their planning systems without the help of IT-experts and give them a greater freedom and speed to adjust when processes or requirements change.

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