Tackling Different Business Process Perspectives
Modeling data, time, and decisions in BPMN processes

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Modeling has always been at the core of organizational and information systems design. Business process models are foundational to all the phases of the BPM life-cycle and cover different aspects depending on the final modeling purpose. Traditional activity-centric process modeling languages focus on capturing the logical flow of activities while leaving other perspectives poorly supported. By taking BPMN as a reference, this thesis aims to investigate how and to which extent, existing activity-centric process modeling languages may be used to capture the temporal, informational, and decision perspectives of business processes, prompting a novel viewpoint on multi-perspective process modeling.

1 Introduction and Motivation

Business processes are key instruments for understanding and improving the way a company or organization operates and produces value [19]. Business process models lie at the core of business process management (BPM) and consist of the explicit representation of business processes through models that follow a specific purpose [14] and encompass multiple perspectives [18].

Traditionally, notations for process modeling are activity-centric, that is, they focus on representing activities and their logical order of execution (i.e., the so-called control-flow perspective). Among them, the Business Process Model and Notation (BPMN) [15] has established itself as the standard language for process modeling and is widely used in both academic and industrial environments.

However, BPMN combines functional and behavioral aspects [11], while lacking support towards other modeling perspectives, such as the temporal, informational, and decision perspectives among others.

The *temporal perspective* (or time perspective) deals with the representation and management of time-related aspects and constraints that need to be obeyed during process execution [18]. In particular, the specification and verification of temporal constraints is crucial for dealing with the time restrictions and requirements dictated by the application domains in which processes are enacted [9]. Nevertheless, the support provided by existing process modeling approaches, such as BPMN, to the specification and run-time verification of temporal constraints is still limited [13].

The *informational perspective* (or data perspective) focuses on the representation of information entities consumed, produced or manipulated by a process, and of the data flow between process activities [18]. However, activity-centric process modeling languages treat data as "black boxes" used as input or output

for activities and provide only elementary ways to represent process access to persistent data sources. In particular, conceptual process and data models are only rarely related and their linkage is handled at the implementation level [4,8].

The *decision perspective* comprises the decision-making that is carried out during process execution, potentially influencing the choice of alternative paths. Recently, the Decision Model and Notation Standard (DMN) [16] has been introduced as a means to foster the separation between process and decision logics. However, separating and integrating process and decision models in a consistent way remains challenging [10]. Indeed, it is not easy for designers to determine which decision aspects embedded in the control and data flows of a process model should be extracted from it and put in a dedicated DMN model [1].

From literature it can be evinced that there is a crucial need for representing different process modeling perspectives [8, 11, 13, 18], possibly improving and integrating existing methods, rather than proposing new, ad-hoc formalisms that tend to be used by a restricted number of users.

In this direction, this thesis starts from the assumption that increased process-awareness requires organizations to integrate process engineering methods with approaches for the management of temporal, data, and decision-making aspects, which have so far received little attention in the field of process modeling. The aim of this work is to investigate how existing modeling approaches coming from the world of information systems engineering may be used or extended to allow process designers to capture the aforementioned perspectives. By relying on consolidated (standard) design methods and languages, the modeling approaches presented in thesis benefit from existing tool support and user experience, and have potential for being (re)used in the field of process modeling.

2 Contributions

This thesis follows the principles of design science and addresses relevant research problems related to multi-perspective process modeling by combining different standard and formal methods for the development and evaluation of each research contribution. The latter ones may be partitioned in three blocks, based on the process modeling perspective they concern.

Requirements were elicited from BPM literature, clinical guidelines, and real-world case studies, mostly coming from healthcare domains, that we explored through different projects in which we were directly involved as BPM experts.

Temporal perspective. This thesis tackles the temporal perspective of business processes by focusing on two main challenges: (1) the specification and runtime management of temporal constraints in BPMN; (2) the use of formal models to verify the soundness and temporal properties of time-aware process models. (1) This thesis introduces a modular approach to specify different nuances of duration constraints for process activities and regions in BPMN processes [7]. We design a set of reusable and well-structured duration patterns that can be combined with the activity/process region to constrain, forming a duration-aware

process model that behaves according to BPMN semantics [6]. Our proposal exploits the advanced event handling mechanisms included in BPMN to capture the flowing of time, to realize synchronization between different branches of the same process, and to detect the violation of duration constraints at run-time. Instead, for specifying more complex time constraints, such as time lags and contingent durations, i.e., durations whose value is observed during the process run-time only once the activity has completed, we add a temporal dimension to selected BPMN elements and provide the semantics through formal models [17]. (2) Mappings towards formal models, i.e., time Petri nets, timed automata, and conditional simple temporal networks with uncertainty and decisions (CSTNUDs), are provided to verify the soundness of the proposed process models and to check the dynamic controllability property [17]. The use of different formal methods for verification purposes depends on the kind of temporal constraints considered (e.g. intra or inter-activity ones) and on the final goal. Time Petri nets are preferred to check the soundness of the process models used to capture duration constraints; timed automata are used to pave the path towards the checking of time constraints with existing tools; CSTNUDs are considered to capture contingent durations along with the decision-making enacted during execution to ensure that temporal constraints are observed.

Informational perspective. Among the many challenges concerning the integration of processes and data [12], this thesis focuses on the modeling of persistent data and on capturing the relation between processes and databases, considering also potential inconsistencies arising from erroneous data access [3]. The added value of this contribution is the definition and experimental evaluation of the *Activity View*, a novel conceptual view aimed to capture the connection between a BPMN process model and the UML schema of a database [4]. The goals of the Activity View are (i) to support process designers in modeling the operations performed by process activities on a database and (ii) to enable basic reasoning on the interplay between connected process and data models. The proposed Activity View is evaluated through a controlled usability study.

Regarding (ii) we devise an approach for storing and querying integrated process and data models by taking advantage of relational database approaches. In detail, we propose an algorithm to collect all the information related to a process model, a conceptual database schema representing a persistent data source for the process, and the data operations performed by the process on the database, and provide sample SQL queries able to answer questions about connected process and data models (e.g., are there alternative process activities that need to have reading access the same data?). As for the detection of data inconsistencies, we rely on Activity Views to derive sequences of data access operations performed on a database and check whether their order, dictated by the process control-flow, leads to inconsistent data (e.g., missing or duplicated data) [3].

Decision perspective. Following the recent introduction of the DMN standard [16], this thesis deals with the modeling of decisions made within BPMN processes, specifically focusing on the needs of knowledge-intensive processes.

Starting from the assumption that decisions have long been encoded into business processes [1], we shed light on the use of data for decision-making typically

represented in BPMN process models through data-aware elements. Then, we define a pattern-based approach to ease the derivation of DMN decision models from the data perspective of process models [2].
Moreover, this thesis explores the benefits brought by the joint use of BPMN and DMN for modeling and standardizing decision-intensive care pathways, i.e., structured care plans that detail which are the essential care activities that need to be performed to treat a specific category of patients. To this end, we propose a methodological framework, inspired by the traditional BPM life-cycle, aimed to define reference steps for designing and simulating healthcare processes in a standard way that can easily be understood and shared by stakeholders [5]. Healthcare working environments allowed us to define contact points between different process perspectives and to elaborate on the overall contributions of this thesis with respect to real and complex application scenarios.

3 Implications for Future Research

Overall, this thesis sheds light on the field of multi-perspective process design and analysis by tackling the modeling of temporal, informational, and decision aspects in BPMN processes. Some of the research questions addressed in this thesis were elicited from real-world process models, thus confirming that the need of modeling complex, high-level aspects is still a current issue in BPM practice. Moreover, it is clear from literature [8, 10, 13, 18] that each of the considered perspectives has still room for improvement along different directions.

The data perspective is indeed a promising direction for future research. A natural continuation of the results presented in this thesis is the improvement of process and data integration [12], which remains an open challenge in the BPM field. Especially since processes are more and more integrated with (big) data coming from different sources, there is the need to support designers in (i) representing data having different structure and granularity and (ii) managing such data efficiently to extract high-level knowledge and enable decision-making.

Along this line of thought, we aim to carry on with conceptualizing the integration of processes and data, by considering different levels of process abstraction and a broader range of data related to processes. Indeed, the Activity View in its current form addresses the conceptual modeling of persistent data sources that are "external" to the process itself, without considering volatile data that are part of the process itself, e.g., process variables, or data that are part of the domain knowledge at disposal of stakeholders.

Eventually, since most of the approaches presented in this thesis rely on standard languages, we advocate that they may be considered to enhance the support provided by existing process modeling tools for different process perspectives.

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