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Enabling flexible location-aware business process modeling and execution

Xinwei Zhu [a,*], Seppe vanden Broucke [b], Guobin Zhu [a], Jan Vanthienen [b], Bart Baesens [b,c]

[a] International School of Software, Wuhan University, Luoyu Road 37, Hongshan, Wuhan, Hubei, China
[b] Research Center for Management Informatics (LIRIS), KU Leuven, Naamsestraat 69, B-3000 Leuven, Belgium
[c] School of Management, University of Southampton, Highfield Southampton SO17 1BJ, United Kingdom

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A B S T R A C T

Business process management (BPM) has emerged as one of the abiding systematic management approaches in order to design, execute and govern organizational business processes. Traditionally, most attention within the BPM community has been given to studying control-flow aspects, without taking other contextual aspects into account. This paper contributes to the existing body of work by focusing on the particular context of geospatial information. We argue that explicitly taking this context into consideration in the modeling and execution of business processes can contribute to improve their effectiveness and efficiency. As such, the goal of this paper is to make the modeling and execution aspects of BPM location-aware, i.e. to govern and constrain control-flow and process behavior based on location-based constraints. We do so by proposing a Petri net modeling extension which is formalized by means of a mapping to colored Petri nets (CPNs). Our approach has been implemented using CPN Tools and a simulation extension was developed to support the execution of location-aware process models. We also illustrate the feasibility of coupling business process support systems with geographic information systems by means of an experimental case.

1. Introduction

Throughout the past two decades, business process management (BPM) has emerged as one of the abiding systematic management approaches to align organizational business processes to the needs of clients [34]. BPM encompasses a broad scope, including the design, modeling, execution, monitoring and optimization of business processes — the so-called BPM life cycle [33]. The main driving rationale for BPM is that it enables organizations to be more efficient and more capable to react to changes. From this viewpoint, BPM regards processes as core strategic assets of an organization, which hence need to be understood, managed, and improved to increase the value added by products or services delivered to clients.

The emergence of BPM has caused a shift in the realm of information systems and information technology from data-based information systems to process-aware ones, i.e. "Process-Aware Information Systems", or PAIS. The support provided by PAIS — be it for the modeling, execution, validation or monitoring of business processes — is only able to capture and describe an idealized or simplified version of reality. Traditionally, most attention within the BPM community has been focused on studying control-flow aspects of business processes, i.e. the aspects governing the flow of business activities (i.e. the sequence in which activities can be performed). In recent years, however, integrating other perspectives and "contexts" within this view has received increased attention, as support systems which adopt a control-flow-centric view are unable to adequately capture human behavior due to lack of descriptions of possible constraints against activity modeling. Similarly, support systems focusing only on data aspects fail to capture the flow and sequence aspects of the data as it moves through a business process. As such, many scholars have shifted towards studying various approaches that integrate control-flow with other contexts. In this paradigm, processes can be rapidly changed and adapted to a new external data-governed context (e.g., location and weather). It is recognized that contextualizing processes in this manner allows for a more explicit consideration of the environmental setting of a process [30].

This paper contributes to the research field of BPM by focusing on the particular *context of geospatial information*, an aspect which is becoming more and more important in all information system related areas, given the increased usage of mobile devices and tracking as well as other recent developments such as the Internet of Things or sensor-based data gathering. We hence argue that taking this context into account in the various life cycle steps of BPM can contribute to improve the effectiveness and efficiency of process management. Especially in environments where a need arises to apply both process-aware and Geographic Information Systems (GIS), it is highly valuable to combine and integrate these two perspectives, instead of considering them in isolation [24]. The goal of this paper is thus to make the modeling and execution aspects of BPM "location-aware". We do so by proposing

* Corresponding author.
E-mail addresses: xinwei.zhu@whu.edu.cn (X. Zhu), seppe.vandenbroucke@kuleuven.be (S. vanden Broucke), gbzhu@whu.edu.cn (G. Zhu), jan.vanthienen@kuleuven.be (J. Vanthienen), bart.baesens@kuleuven.be (B. Baesens).

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business process modeling language based on a formal Petri net extension which incorporates location aspects and ways to constrain the execution of activities by location-based constraints. Next, we formalize the execution semantics of our extension by describing a unambiguous mapping to colored Petri nets. This also allows us to develop a prototype implementation of our approach using CPN Tools [17], with which a simulation extension was developed to support the execution and validation of models created using our approach and to illustrate the feasibility of coupling business process support systems with geographic information systems.

The remainder of this paper is structured as follows. Section 2 provides an overview of related work and preliminaries used throughout the paper. Section 3 outlines a running example which will be used to illustrate the developed artifacts. Section 4 introduces our proposed modeling language to design location-aware processes, after which Section 5 discusses the execution semantics of such models by means of a mapping to colored Petri nets. Section 6 discusses the developed implementation. Section 7 concludes the paper and provides outlines for future work.

2. Preliminaries

2.1. Related work

We regard location as one of the key variables in the wider context of a business process. In the layered process context model proposed by Rosemann et al. [30], location describes an important variable situated in the environmental context layer, which describes process-related variables that reside beyond the business network in which an organization is embedded, but still pose a contingency effect on the business processes. Scholars have argued that the inclusion of location contextual variables in business process management practices helps to improve dependency aspects (constraining activity executions based on location aspects, for instance) [10], increase the adaptability and flexibility of running processes (by reconfiguring and modifying models and tasks based on location aspects) [14,7,1,5], and improve the efficiency (performance and cost-effectiveness) of organizational processes [35]. Naturally, these concerns are of an even greater importance for processes where mobility (that is, tracking changes in locations and adapting processes to these changes) is deemed to be an important factor [19].

The notion of location-awareness centers around the basic idea that location and location-based services can be sensed and adapted to within processes. Location-aware business process management thus encompasses the ability for a business process to sense the current process status in a specific location and to be aware of the whole process situation. Based on this, process owners can react or dynamically change the process execution to adapt the goal of the process. Examples of location sensitive services and applications can be observed in areas such as navigation and travel, device and human tracking, geosocial networking, retail and real-estate services, mobile workforce deployment, and many others. However, works around the connection of location services with principles of business process management are relatively scarce in the literature. That is, many researchers focus on connecting spatial-based information with scientific workflows [23,2,15,31,3,22,18], but not with business-oriented workflows. As a notable exception, [21] discusses map metaphors that are used to visualize work items and resources in process-aware information systems (using the YAWL workflow language). This technique specifies that users could check geographical positions and distances based on a geographical map, but does not indicate how exactly geographical aspects can influence the flow of execution of the process. Decker et al. [10,11] have defined location constraints for individual workflow activities when modeling a workflow schema to restrict the location where an activity can be performed, but the location constraints lack comprehension and expressiveness. Our proposed modeling technique, on the other hand, is able to specify in an exact manner how location impacts the basic logical relationships in a process control-flow, i.e. sequence, parallel split/joins and exclusive choice split/joins.

Some existing BPM tool suites allow for the definition and capture of additional variables in the modeling of business processes [28,29,19,1]. In theory, such attribute fields could be used to capture location-based information. For instance, in business process model and notation (BPMN) models, locations could theoretically be modeled through the use of swimlanes, text annotations or data elements. In event-driven process chain (EPC) models, location variables may be grouped via organizational objects and in yet another workflow language (YAWL) models, static attributes could be attached to work items as additional text information. However, in all these approaches, location-based elements exist only as secondary constructs or text-based annotations for readers to understand the graphical diagram, and do not impact the semantics or execution of the modeled process in a direct way.

Our approach aims to make location-based constructs first-class citizens in the modeling and execution of process models: meaning that it is possible to govern the execution of a process based on location-based properties, and to signal changes to location properties based on the enactment of activities within a running business process.

2.2. Definitions and notations

This section outlines preliminary concepts and definitions which will be utilized in the remainder of the paper.

Petri nets are a well-known representational language to model concurrent system, and have also been extensively applied to formalize business process model semantics [25,27].

Definition 1. Petri net. A Petri net is a triple (P,T,F) [25,27] with:

- P is a finite set of places, $P=\{p_1,p_2,\ldots,p_{|P|}\}$;
- T is a finite set of transitions, $T=\{t_1,t_2,\ldots,t_{|T|}\}$, with $P\cap T=\varnothing$;
- $F\subseteq(P\times T)\cup(T\times P)$ is a finite set of directed arcs (flow relation).

A place (drawn as a circle, see for instance Fig. 1) $p\in P$ is called an input/output place of a transition (drawn as a box and labeled; unlabeled transitions are shown as a black box) $t\in T$ if there exists an arc from p to t or from t to p respectively. $\bullet t$ and $t\bullet$ denote the set of input and respectively output places for a transition $t\in T$. Similarly, $\bullet p$ and $p\bullet$ define the set of transitions having $p\in P$ as an input place and the set of transitions having $p\in P$ as an output place respectively.

Definition 2. Marking, marked Petri net. A marked Petri net is a triple (N,M,M_0) with:

- $N=(P,T,F)$ a Petri net (a marked Petri net can also be written in an expanded notation (P,T,F,M,M_0));
- $M:P\rightarrow\mathbb{N}_0^+$ is a marking function;
- $M_0:P\rightarrow\mathbb{N}_0^+$ is the initial marking function.

Places $p\in P$ in a Petri net can contain zero or more "tokens" (drawn as black dots inside the places). The distribution of tokens over the places defines the state, denoted as the "marking" of the Petri net, represented by the marking function M, which maps each $p\in P$ to a natural, positive number, representing the amount of tokens contained in that place. The multiplicity of a place p in a marking M, i.e. $M(p)$, denotes the number of tokens that this place contains. The initial marking M_0 is used to initialize all places with an initial token count (in most cases, the initial marking is defined as follows: $M_0:p\in P\mapsto 1$ if $\bullet p=\varnothing$ or 0 otherwise).

Definition 3. Petri net execution semantics. The number of tokens in a Petri net changes during the execution of a Petri net. The marking of a Petri net defines a state, based on which execution semantics can be formalized as follows:

- A transition $t\in T$ is said to be enabled under marking M iff each of its input places contains at least one token: $\forall p\in\bullet t:[M(p)>0]$;