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Constraint-centric workflow change analytics

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ABSTRACT

In a globalized economic environment with volatile business requirements, continuous process improvement needs to be done regularly in various organizations. However, maintaining the consistency of workflow models under frequent changes is a significant challenge in the management of corporate information services. Unfortunately, few formal approaches are found in the literature for managing workflow changes systematically. In this paper, we propose an analytical framework for workflow change management through formal modeling of workflow constraints, leading to an approach called Constraint-centric Workflow Change Analytics (CWCA). A core component of CWCA is the formal definition and analysis of workflow change anomalies. We operationalize CWCA by developing a change anomaly detection algorithm and validate it in the context of procurement management. A prototype system based on an open-source rule engine is presented to provide a proof-of-concept implementation of CWCA.

1. Introduction

To be competitive in the global market, companies need to quickly adapt their business processes to various changes in the business environment, such as mergers/acquisitions, new regulations, and new customer demand. Various changes can occur in different workflow perspectives including control flow, data flow, organizational model, and workflow constraints. For instance, process reengineering or supply chain reconfiguration can lead to the alteration of task execution sequences and removal of non-value-added tasks, i.e. control flow changes. Mergers/acquisitions can result in resource reallocation and organization restructuring, i.e. organizational model changes. New governmental regulations such as the Sarbanes-Oxley Act may require new and revised business rules to be compliant, i.e. workflow constraint changes.

Existing research on workflow changes tends to focus on a limited number of perspectives of workflow, mostly control flow and data flow, paying little attention to dependencies among all workflow perspectives [13,15,22,29,40,44,45,53]. For example, industrial reorganization such as mergers/acquisitions may result in removing certain organizational roles, i.e. an organizational model change. Consequently, tasks assigned to those roles must be delegated to other resources, and the relevant workflow constraints must be revised properly; otherwise, a runtime role resolution error might occur and the corresponding tasks will not be executed. Given these frequent changes in business workflows, managing multi-perspective workflow changes is imperative in order to support business operations and continuous process improvement efficiently.

Many process modeling specifications have been used in practice, such as UML activity diagrams, BPMN, and Event-driven Process Chains (EPCs), but these specifications usually lack analytical capability and therefore cannot be used to formally model and analyze workflow changes. Formal languages have been applied to model workflows, such as Petri nets [1,34,52], Metagraphs [5], Communicating Sequential Processes (CSP) [58], formal logic [10,21], and PI Calculus [46]. In addition, several rule languages have been applied to analyze workflow constraints and specify workflow exceptions [9,13–15]. Nevertheless, little research is found on formal approaches that focus on workflow change analysis treating a workflow system as a whole.

In this paper, we aim to fill this research gap by proposing an analytical framework for managing multi-perspective workflow changes via formal modeling of workflow constraints, referred to as Constraint-centric Workflow Change Analytics (CWCA). The contributions of this paper are as follows. First, we propose a novel constraint-centric approach to analyzing multi-perspective workflow changes by specifying workflow change operations and dependencies formally. Second, we apply First Order Logic to formally define workflow change anomalies and develop an algorithm to detect those anomalies. Third, we validate the CWCA framework through a prototype system that provides insights into the integration of CWCA with existing workflow management systems and rule engines.

The rest of the paper proceeds as follows. We first review the relevant literature in Section 2. Then, we discuss the types of workflow changes and their dependencies in Section 3. In Section 4, we present a procurement process as a running case for the paper and propose a constraint-centric workflow modeling framework to specify different workflow perspectives for formal workflow change analysis. In Section 5, we formally define and analyze workflow change anomalies

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and develop an anomaly detection method. A proof-of-concept system is also presented to demonstrate CWCA and validate the anomaly detection algorithm. We compare our framework with some other related approaches and discuss its limitations in Section 6. Finally, we conclude in Section 7 by summarizing our contributions.

2. Literature review

The structural perspective of workflow modeling is captured by control flow [49]. A control flow model usually indicates the tasks, their execution sequences, and the corresponding transition conditions. There have been extensive research efforts on control flow modeling, resulting in many process modeling methods. UML activity diagrams, EPCs, and BPMN are widely adopted graphical business process modeling standards. However, they lack a rigorous mathematical foundation and therefore have limited analytical capability. Petri nets have been used to represent and analyze process models [1,52]. A number of Petri nets extensions have been proposed including timed Petri nets and colored Petri nets, which have been used to model data flow, temporal constraints, and workflow events [8,28,34]. Many workflow structural properties such as reachability, deadlock, and livelock, can be formally verified using Petri nets. Tools have also been developed to support Petri-nets-based workflow modeling and simulation such as CPN Tools (http://wiki.daimi.au.dk/cpntools) and YAWL (http://www.yawl-system.com/). Metagraphs are another rigorous process modeling approach with mathematical foundation and strong analytical capability [5]. Metagraphs provide three different views of a process model, namely, task view, data view and resources view and are able to analyze interactions among those three views via matrix computations [5]. Various logic formalisms have also been applied to workflow modeling and analysis, such as propositional logic, temporal logic, event algebra, and concurrent transaction logic [10,21,38]. One unique feature of logic-based approaches is the capability to model and enforce various constraints on task dependency and execution orders. Communicating sequential process (CSP) [58] and Pi-calculus [46] have also been applied to represent workflow, where model checking techniques can be used to verify certain workflow properties.

Organizational modeling in workflow has been identified as an important research area in business process management [7], which provides the organizational context of workflow applications. Several organizational meta-models have been proposed to make workflow management systems more “organizational aware” [61]. The specification and validation of data flow in workflow system is critical, because data flow anomalies may prevent workflows from proper execution if not detected prior to workflow deployment [45,50]. Specifically, Sun et al. (2006) identify three types of data anomalies, namely missing data, redundant data, and conflicting data, and propose a data anomaly verification algorithm. The proper execution of workflows requires authorization constraints to enforce the assignment of tasks to organizational resources, such as human users, roles, organization units, or machine agents [15]. Different mechanisms have been proposed to specify and enforce workflow authorization constraints, such as Secure Petri Nets [3], logic-based constraint specification [9] and ECA (event-condition-action) rules [15].

Curtis et al. proposed four perspectives in process representation, namely, functional, informational, organizational, behavioral perspectives [19]. Functional perspective models what process elements are being executed, and what flows of informational entities, are relevant to the process elements. Informational perspective specifies the informational entities produced or manipulated by a process. Organizational perspective defines where and by which agents in the organizational model that process elements are performed. Behavioral perspective concerns with when and how process elements are performed through different workflow structures. In this paper, the four perspectives are substantiated via control flow, data flow, and organizational model, and workflow constraints, which are well-known concepts in workflow modeling. More specifically, control flow is related to both the functional and behavioral perspectives; data flow mainly models the informational perspective, organizational model specifies the organizational perspective; and workflow constraints serve as the glue to all four perspectives.

Another related research area is business rules research. Many rule representation languages have been developed to express business rules, enable rule reasoning, and facilitate rule extraction, reuse and integration [14,41]. There have been extensive implementation efforts in rule engines and development tools, such as JESS, CLIPS, and Drools. As a key enabling technology for process management, workflow technology has been applied in services computing research areas such as web services orchestration and choreograph [60], web-service-based process integration [11], and web-service-enabled process management for collaborative commerce[16]. A number of languages have been proposed to describe the process models of web services, such as Business Process Execution Language (BPEL) for web service orchestration [2], Web Services Choreography Description Language (WS-CDL) for web service choreography [30], XML Process Description Language (XPDL) for business process definition interchangeability [57], and First-order Logic Ontology for Web Services (FLOWS) [51]. In particular, FLOWS is developed by extending the Process Specification Languages (PSL) [25], which is based on First Order Logic. The goal of FLOWS is to enable reasoning about web service semantics by providing a fully expressive language and framework for modeling semantic aspects of service behavior [26]. Nevertheless, none of the languages list above is designed for analyzing multi-dimensional workflow changes. Our research in this paper leverages First Order Logic to model workflow changes and change consequences among different workflow perspectives, which can be incorporated into other languages and frameworks, e.g. FLOWS, to provide analytical capability for handling workflow changes.

Organizations are recognizing that workflow management systems must be able to adapt efficiently to changes in business in order to realize the real power of process automation [29]. As such, research in dynamic and adaptive workflow has received much attention [12,40]. Sadiq et al. (2000) found that changes to workflow models are often permanent as the result of process improvement, process reengineering, merger/acquisitions, etc., whereas changes in workflow instances are usually due to unforeseen and rare situations in process operations. They defined five workflow modification policies to cope with workflow changes, namely, Flush, Abort, Migrate, Adapt, and Build [44]. Change management involves thorough analysis of process structure and current process status in order to avoid process errors known as “dynamic change bugs” [53]. Several mathematical models have been proposed to formally represent workflow dynamic changes and identify “safe” ways to migrate existing instances without incurring dynamic change bugs [22,40,53]. Change adaptation means that there are some instances that need to be treated differently due to exceptions defined as “deviations from an ideal collaborative workflow process caused by errors, failures, resources or requirements changes” [31]. Different methods for exception specification and handling have been proposed in the literature, such as knowledge-based approach [31], active rule based approach [13], and meta modeling approach [17].

In sum, most previous works have focused on some limited perspectives of workflow changes such as those in terms of control flow and data flow, leaving out other important perspectives such as changes in organizational models and workflow constraints. In addition, research on formal approach to analyzing multi-perspective workflow changes has been scant. As such, systematic and comprehensive multi-perspective change management features are virtually not found in existing workflow management systems.

3. Workflow changes and dependencies

In this section, we first discuss various changes in different workflow perspectives, including control flow, data flow, organizational model, and workflow constraints. Then, we show how workflow consistency