Extended event–condition–action rules and fuzzy Petri nets based exception handling for workflow management

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ABSTRACT

Exception handling plays a key role in dynamic workflow management that enables streamlined business processes. Handling application-specific exceptions is a knowledge-intensive process involving different decision-making strategies and a variety of knowledge, especially much fuzzy knowledge. Current efforts in workflow exception management are not adequate to support the knowledge-based exception handling. This paper proposes a hybrid exception handling approach based on two extended knowledge models, i.e., generalized fuzzy event–condition–action (GFECA) rule and typed fuzzy Petri net extended by process knowledge (TFPN-PK). The approach realizes integrated representation and reasoning of fuzzy and non-fuzzy knowledge as well as specific application domain knowledge and workflow process knowledge. In addition, it supports two handling strategies, i.e., direct decision and analysis-based decision, during exception management. The approach fills in the gaps in existing related researches, i.e., only providing the capability of direct exception handling and neglecting fuzzy knowledge. Based on TFPN-PK, a weighted fuzzy reasoning algorithm is designed to address the reasoning problem of uncertain goal propositions and known goal concepts by combining forward reasoning with backward reasoning and therefore to facilitate cause analysis and handling of workflow exceptions. A prototype system is developed to implement the proposed approach.

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1. Introduction

Workflow management is nowadays considered as a key technology to improve the effectiveness and productivity of complex collaborative business processes, such as healthcare processes and order fulfillment processes (Lenz & Reichert, 2007; Ye, Yang, Jiang, & Tong, 2006). Its main principle includes the realization of dynamic workflow enactment, monitoring and administration on the basis of explicit workflow specifications of these processes. Due to differences or changes of workflow participants (including human actors and existing applications) and environment, a broad range of exceptions usually occur during workflow execution. The exceptions are generally defined as deviations from prescribed normal flows of the processes and need to be effectively addressed for satisfactory, efficient process outcomes. Exception handling has

been recognized as a key issue and challenge in this field and has received much attention from many researchers and projects.

Workflow exceptions include failures at system level and at software application level, e.g., disk breakdown, operating system crash, and program constraint violations in the workflow execution environment. These exceptions normally can be handled by some extended ACID (atomicity, consistency, isolation, durability) transaction models (Atluri, Huang, & Bertino, 2000; Grefen, Vonk, & Apers, 2001; Hagen & Alonso, 2000; Nagi, Nims, & Lockemann, 2001). Other exceptions are mostly related to the application domain of workflow management system, especially domain objects and resources. For example, in the healthcare workflow management, a physician requests the use of special drugs and a patient shows an abnormal symptom. The two exceptions are related to healthcare professionals and service objects in the healthcare domain. Such exceptions can be called application-specific exceptions.

The occurrence of an application-specific exception actually initiates an exception handling decision-making process. The process is a knowledge-intensive process involving a variety of knowledge, e.g., specific application domain knowledge and workflow process knowledge. Furthermore, it interrelates and interacts with standardized workflow execution, as shown in Fig. 1. It may suggests
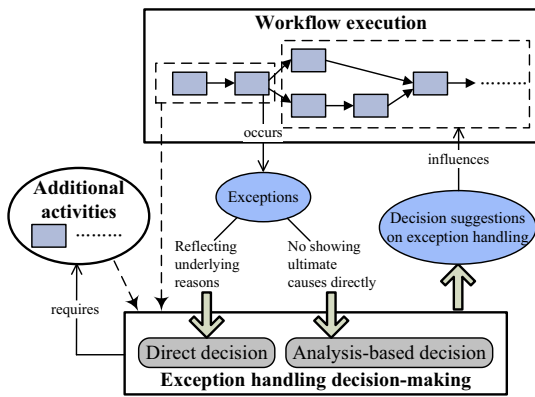
Fig. 1. The exception handling decision-making process and its relationships with standardized workflow execution.

the executions of additional activities for analyzing exceptions to workflow process and finally offers decision suggestions on exception handling and possible subsequent process change through knowledge reasoning. Then, workflow execution can continue after appropriate modification based on these suggestions.

The knowledge-intensive process typically contains two handling strategies, as shown in Fig. 1. Some exceptions themselves reflect underlying reasons for their occurrences. They generally include the exceptional events related to behaviors of human actors and improper states of resources, e.g., a physician's special request. Their handling decisions usually can be directly made based on established knowledge, such as management policies and business rules of application organizations. For example, a hospital specifies that physicians' special requests are accepted if they can provide reasonable reasons. Thus, the request exception can be handled according to the organizational rule. Such handling strategy is called direct decision. In addition, other exceptions do not directly show their ultimate causes, e.g., abnormal situations about treatment and state of domain objects. The causes need to be first analyzed and then proper handling measures are determined by combining different relevant knowledge and possibly performing additional activities. In other words, a strategy of analysis-based decision is adopted. For instance, a patient has a high fever before scheduled surgery during predefined care process. The exception can be properly handled only after underlying reasons for the fever are ascertained.

In addition, the knowledge-intensive process may involve much imprecise knowledge in the application domains. The knowledge usually contains linguistic terms without clear-cut interpretations for representing fuzzy concepts and relationships with blurred boundaries. For instance, 'reasonable reason' is a fuzzy concept using the linguistic term 'reasonable'. In certain workflow application domains (e.g., healthcare domain), the descriptions of activity results may be vague. For example, lochia volume is the result of the lochia assessment activity. It is normally not described by concrete numerical values but by such linguistic terms as 'large', 'medium', and 'small'. Additionally, the knowledge mostly contains fuzzy relationships. For instance, handling a healthcare workflow exception may use the following statement: acute bronchitis often results in fever. The knowledge indicates that there exists causal relationship between the acute bronchitis disease and the fever symptom to a certain extent, rather than the polar relationship of the disease definitely causing or not causing the symptom.

Based on the above analysis, an approach to handling application-specific workflow exception is supposed to address the following problems: (1) the support of two handling strategies (i.e., direct decision and analysis-based decision); (2) integrated representation and reasoning of different relevant knowledge (e.g.,

specific application domain knowledge and process-related knowledge), especially fuzzy and precise knowledge. However, current efforts are mostly focused on providing the capability to directly handle exceptions and have not been found to meet these requirements.

In this paper, we propose a knowledge-based hybrid exception handling approach to support direct decision and analysis-based decision strategies. The approach is based on two extended knowledge models: generalized fuzzy event–condition–action (GFECA) rule and typed fuzzy Petri net extended by process knowledge (TFPN-PK). They are presented by introducing fuzzy set theory (Zadeh, 1965, 1973) and building knowledge semantic associations. A TFPN-PK-based weighted fuzzy reasoning algorithm (TFPN-PK-WFRA) is also developed to realize integrated representation and reasoning of fuzzy and non-fuzzy knowledge as well as application domain knowledge and workflow process knowledge. In addition, the handling of exception cases in the healthcare workflow management and the prototype implementation are used to demonstrate the applicability of the proposed approach in managing workflow exceptions.

The remainder of this paper is organized as follows. An overview of related work is given in Section 2. Section 3 presents the hybrid approach and explains GFECA rule and direct exception handling based on the model. Based on a running example, exception analysis and handling method based on TFPN-PK and its fuzzy reasoning algorithm is discussed in Section 4. Section 5 describes the developed prototype. Finally, conclusions are given in Section 6.

2. Related work

There have been numerous researches on workflow management using Petri nets (Bratosin, van der Aalst, & Sidorova, 2007; Cheng, Liu, & Yang, 2005; Jørgensen, Lassen, & van der Aalst, 2008; Quaglini, Stefanelli, Lanzola, Caporusso, & Panzarasa, 2001; Russell, ter Hofstede, & van der Aalst, 2007; Russell & van der Aalst, 2008; van der Aalst, Aldred, Dumas, & ter Hofstede, 2004; van der Aalst & ter Hofstede, 2005; van Hee, Serebrenik, Sidorova, & van der Aalst, 2007; Wang & Zeng, 2008). van der Aalst and ter Hofstede (2005) proposed *yet another workflow language* (YAWL) based on Petri nets and workflow patterns (van der Aalst, ter Hofstede, Kiepuszewski, & Barros, 2003) and developed a workflow management system supporting YAWL. Later on, Russell and van der Aalst (2008) designed a revision of YAWL, namely newYAWL, and relevant system based on colored Petri nets (CPNs). Jørgensen et al. (2008) presented an approach to implementing care workflow systems by constructing two executable models, i.e., executable use case (EUC) and colored workflow net (CWN), of healthcare processes using CPN and then translating CWN into YAWL specification. Wang and Zeng (2008) presented a modeling and analysis approach for workflows constrained by resources and non-determined time using a kind of Petri net, where activities are represented by places. Most of them are concerned with modeling, stimulation, validation and analysis of workflow process based on different classes of Petri nets. In this paper, we focus on integrated knowledge modeling and reasoning by using and extending fuzzy Petri nets (FPNs) (Chen, 2000, 2002; Jiang, 2004) for facilitating exception analysis and handling during the execution of workflow process.

With extensive researches and applications of workflow management, much research efforts have been focused on issues related to adaptive workflows, which range from exception handling to workflow evolution. Several reviews of these researches can be found in Russell, van der Aalst, and ter Hofstede (2006) Rinderle, Reichert, and Dadam (2004). In terms of exception management, ECA rules have been adopted and extended by many