Available online at www.sciencedirect.com
SCIENCE DIRECT®
Information Systems 30 (2005) 399–422
www.elsevier.com/locate/infosys

An architecture for workflow scheduling under resource allocation constraints

Pinar Senkul*, Ismail H. Toroslu

Department of Computer Engineering, Middle East Technical University 06531 Ankara, Turkey

Received 22 November 2002; received in revised form 4 March 2004; accepted 19 March 2004

Abstract

Research on specification and scheduling of workflows has concentrated on temporal and causality constraints, which specify existence and order dependencies among tasks. However, another set of constraints that specify resource allocation is also equally important. The resources in a workflow environment are agents such as person, machine, software, etc. that execute the task. Execution of a task has a cost and this may vary depending on the resources allocated in order to execute that task. Resource allocation constraints define restrictions on how to allocate resources, and scheduling under resource allocation constraints provide proper resource allocation to tasks. In this work, we provide an architecture to specify and to schedule workflows under resource allocation constraints as well as under the temporal and causality constraints. A specification language with the ability to express resources and resource allocation constraints and a scheduler module that contains a constraint solver in order to find correct resource assignments are core and novel parts of this architecture.

Keywords: Workflow; Scheduling; Resource; Resource allocation constraints; Constraint programming

1. Introduction

Workflow is a collection of tasks organized to accomplish some business process. It also defines the order of task invocation or conditions under which task must be invoked, task synchronization, and information flow [1]. Patient treatment in a hospital, banking services, manufacturing and catalog ordering processes and many more activities in today's business life can be modeled as workflow. The nature of the tasks in a workflow may vary considerably. These tasks may be manual jobs or computer programs that execute on different platforms. A workflow management system (WFMS) provides a model and tools for specification, analysis, and execution of workflows. It forms a framework to capture the relations among the tasks (i.e., the business logic of the workflow), to gather the tasks with different nature and to automate the execution

*Corresponding author. Tel.: +90-312-210-5518; fax: +90-312-210-1259.
E-mail addresses: karagoz@ceng.metu.edu.tr (P. Senkul), toroslu@ceng.metu.edu.tr (I.H. Toroslu).

0306-4379/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.is.2004.03.003

in such a way that it obeys the business logic. The correct definition and execution of the workflow means more quality and less cost for an establishment. For this reason, workflows have been an attractive research area. Surveys on the subject can be found in [1–6,49].

Scheduling of workflows is a problem of finding a *correct* execution sequence for the workflow tasks, i.e., execution that obeys the constraints that embody the business logic of the workflow. Approaches in this area are typically based on temporal logic and specialized algebras [7–9], Petri nets [10,11], and concurrent transaction logic and other logics for representing actions [12–16]. Research on workflow scheduling has largely concentrated on temporal and causality constraints, which specify existence and order dependencies among the tasks. For instance, *task* 1 *must execute before task* 2 or *if task* 1 *executes*, *task* 2 *must execute as well* (also known as Klein's existence constraint [17]) are examples of temporal/causality constraints considered in [7,9,15].

However, another set of constraints that specify resource allocation are equally important. Examples of resources in a workflow are agents such as person, machine, software, etc. that execute the task. Resource allocation constraints define restrictions on the resources of the workflow. Execution of a task has a cost, in terms of money, time etc., and this may vary depending on the resources allocated in order to execute the task. Although resource management has been recognized as an important aspect of a WFMS, most of the work has focused on modeling issues [2,10,18] or agent behavior in workflow systems [19–21] with little attention devoted to scheduling. Scheduling under resource allocation constraints include decisions on which resources to allocate and when to allocate them and thus provide proper resource allocation. It seems natural to include resource allocation constraints into the workflow specifications in the areas that require efficient scheduling in order to obtain fast responds to user's demands on the process' budget, duration, etc. as in catalog ordering, manufacturing. Davulcu et al. [22] discusses about constraints that involve execution cost of tasks and that are used for modeling and reasoning of virtual enterprises modeled as workflows. These constraints may be seen as early version for resource allocation constraints.

Simple resource allocation constraints are constraints like *if task* 1 *is executed by some agent*, *task 2 should be executed by the same agent as well.* Moreover, *total cost* <100 is an example of resource allocation constraints in a system where resource allocation to execute tasks has some associated cost values. Cost may consist of one or more of dimensions such as financial expenditure to fulfill the task by a given agent, the execution time, or the energy consumption, etc. Several resources may be available and qualified to perform the given task with different cost values. It is possible to group resources under roles and define hierarchical role structures.

Most of the previous work on workflows concentrated on issues related to run-time check of the constraints. If a workflow is executed before it is verified, its constraints may be checked and a schedule might be obtained incrementally during the execution. However, a workflow specification might be unexecutable because of its incorrect design or conflicting constraints. At some point of the execution, if it is detected that the workflow cannot be completed because of design errors, some rollback operations might be needed before abandoning the execution of the workflow. Obviously, such cases cause waste of resources. Therefore, it is important to verify the given workflow specification, and this verification can be done by obtaining a feasible workflow schedule providing proper resource allocation.

In this work, we present a workflow management system architecture that provides modules to model resources and resource allocation constraints and to find schedules fulfilling these constraints. In order to find schedules, *constraint programming approach* is used. That is, scheduler incorporates an off-the-shelf constraint solver to obtain a feasible schedule for the workflow satisfying both resource allocation and temporal/causality constraints. *Operations research* (*OR*) and *constraint programming* have been successfully used for problems such as *job-shop scheduling*, in which proper machine (i.e., resource) allocation constitutes an important part of the solution. (For more information on constraint programming, reader may refer to [23–26].) However, contrary to most OR problems, our goal is to find a feasible resource allocation rather than finding the optimal solution. A typical constraint solver is not