Proceedings of The Third International Conference on Electronic Commerce(ICeCE2003), Hangzhou Oct. 2003, pp.995-999

Intelligent Workflow Management: Architecture and Technologies

Chen Huang [a], Yushun Fan [b]
Department of Automation, Tsinghua University,Beijing 100084, PR China
(E-mail: [a] hc01@mails.tsinghua.edu.cn; [b] fan@cims.tsinghua.edu.cn)

Abstract

Workflow technology is facing with numerous technical challenges in more complex, dynamic and uncertain environments.We first analyze the requirements for intelligent workflow management systems from the perspective of both workflow and artificial intelligence (AI) field, and conclude that intelligent workflow management should have the ability of explicitly describing and understanding the circumstance where the enterprise situates and the purpose of the business process, then determining what activities to undertake and in what sequence according to its experience, and also adjusting and modifying its actions in response to the change of global market.. Then we present a new process of intelligent workflow management, which is double closed-loop and steady, intelligent and flexible to obtain objectives of organizations. A new architecture of intelligent workflow management system is provided according to this process, main components of which involve modeling, planning, scheduling, monitoring, reactive control and learning tools. Many branches of AI, including planning, scheduling, reactive control, and machine learning, can contribute to this intelligent workflow management system, and as such would be discussed in detail within this paper.

Keywords: artificial intelligence (AI); workflow management (WFM)

1. Introduction

Workflow management (WFM) is one of the focuses that many researchers, developers and users take attentions to in recent years, since WFM systems facilitate the everyday operation of many enterprises and work environments. Consequently, many commercial WFM systems have been developed and found applications in various situations. All of these WFM systems use explicit models and representations of process, along with automated tools that support the activation and ongoing management of a process instance.

However, enterprisers and users find that they are situated in more complex, dynamic and uncertain environments nowadays. Accordingly, existing WFM systems, although have seen an explosion of interest and advances, are now expected to bring benefits in applications characterized by complex tasks performed in dynamic and uncertain environments. For example, it must have the capability to manage processes which cannot be modeled explicitly in advance and to react appropriately to events that cannot be fully modeled in the process definition. Conventional workflow technology is thus faced with numerous technical challenges in order to provide the kind of flexible WFM systems required by these application domains.

Fortunately, we find that the issues mentioned above are exactly what AI researchers have long been dealing with. In contrast to workflow's focus on business processes, the AI community took attentions on the problem of adding some "thinking-like" features to computers to make them more useful tools. It is apparent that the time has come for a marriage of the two technologies to provide an intelligent WFM system to solve the problems we are now facing. In order to do this, not only intelligent functions about autonomous process control should be embedded directly into workflow architecture, but also should workflow architecture become more flexible itself, which indicates that a new intelligent architecture is imperative to integrate both theories and technologies of AI.

Many branches of AI, including planning, scheduling, reactive control, machine learning and so on, are subservient to achieve the objectives for intelligent WFM and thus could contribute to intelligent WFM system, and as such would be discussed in detail within this paper.

This paper is structured as follows. Section 2 provides an overview of workflow management, along with the challenges it faces today. Section 3 analyzes what is intelligent workflow from AI perspective, and then Section 4 and Section 5 presents separately a new process of intelligent workflow management and a new architecture of intelligent WFM system which is not only intelligent in sense of AI but also can meet requirements in workflow field. Section 6 describes how AI technologies integrated in this architecture, including planning, reactive control, scheduling and machine learning, could contribute to provide an intelligent WFM system. Finally, a summary is made in Section 7.

2. Overview of Traditional Workflow

2.1. Introduction of traditional workflow

According to the Workflow Management Coalition (WfMC), a WFM system is “a system that completely defines, manages and executes workflows through the execution of software whose order of execution is driven by a computer representation of the workflow logic.” [1] Figure 1 presents an overview of a generic workflow management system, adapted from the WfMC’s Reference Model. At the highest level, all WFM systems can be characterized by the following functional components:

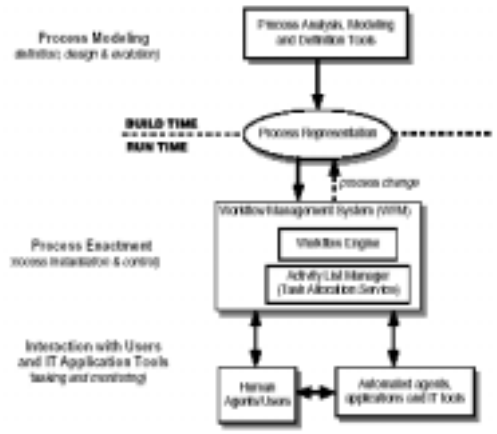

Figure 1: Architecture for Current Workflow Management System Technology

- Modeling and representation of workflow processes
- Instantiation of processes for activation in response to a user's request or key events
- Scheduling and tasking of activities of activated processes
- Monitoring and adaptation of executing processes

Each WFM system has a library of process models, which are formal definitions of business processes and constructed by one or more modeling techniques. As reflected in Figure 1, process modeling and representation are typically limited to build time within current WFM technology. At run-time the process model is interpreted by workflow engine which is responsible for creating and controlling operational instances of the process, scheduling the various activities within the process and invoking the appropriate human and application resources, etc. As part of activation, resource allocation and tasking is performed for new activities based on current resource availability and load balancing. In highly unpredictable and dynamic operating environments, enacted processes must evolve and adapt in response to a number of factors, including changes in the environment, the addition of new tasks, and execution results. Monitoring plays a critical role during enactment of process, to detect key events that may necessitate adaptations to current processes, or enactment of new or different processes.

2.2. New requirements for WFM system

Though there are various commercial WFM systems with different application domains in the market, all of them, abiding by WfMC's reference model, share a common ground: explicit models and representations of process are absolutely requisite in advance, based on which automated tools could support the activation and ongoing management of a process instance.

However, this is not reasonable in more complex, dynamic and uncertain environments, for that it is difficult, or more strictly speaking, impossible to obtain such well-defined process model beforehand. In some cases, the process is too complicated to be described explicitly; in some other cases, the process is completely original that no one could tell what it should be like exactly until a process instance is accomplished. Besides, unlike traditional workflow applications, more and more processes are highly dynamic. There is constant evolution of the tools, techniques, and materials used in a process. The time scale of the process is often counted in months or even years, leading to initially indeterminate changes in personnel, resources, and even the process itself over time. There are many interactions with external events and conditions that cannot be controlled from within the process. All of these contribute to making process management resistant to a traditional workflow approach.

Actually, as workflow has evolved, it has to move from such a fixed way to a more flexible way which no longer relies on static process model and supports the capture and management of the uncertainty and change of processes since application domains demand flexible adaptation to more complex and dynamic environments. These issues are exactly those that AI researchers have long been dealing with. Therefore it is apparent that the time has come for a marriage of the two technologies to provide an intelligent WFM system.

3. What is intelligent workflow: from AI perspective

3.1. Intelligent system

When do we consider a system to be intelligent? The question, like the question "*what is intelligence?*" itself, is not easy to answer. But for the purpose of this paper, an intelligent system is one that is capable of flexible autonomous action in order to meet its design objectives[2]. Typically it should have four properties:

- Reactive: able to perceive their environment, and respond in a timely fashion to changes that occur in it in order to satisfy their design objectives, namely event-driven.
- Proactive: able to exhibit goal-directed behavior by taking the initiative in order to satisfy their design objectives.
- Social ability: capable of interacting with others (and possibly humans) in order to satisfy their design objectives.
- The ability to learn: able to learn from experience and environment.

Reactive systems have various means of sensing their worlds and acting in them. Have no internal state and simply react to immediate stimuli in their environments. We call this stimulus-response. The more complex ones will also have the ability to remember properties and to store internal models of the world. In all cases, the actions taken by reactive systems are functions of the current and past states of their worlds.

Proactive systems have the ability to anticipate the effects of their actions and take those that are expected to lead toward their goals. Such systems can be said to make plans. This ability is criteria for intelligence. Furthermore, systems will usually be more effective if they can take implicit constraints that are analogous to properties of real worlds into account. That means they must be able to reason; they can deduce properties of their worlds that are only implicit in the constraints.

Finally, effective performance then sometimes requires anticipating and influencing what other systems might do. Communication among systems then becomes an important action in itself.

Along with the ability to plan, the ability to learn is thought to be one of the hallmarks of an intelligent system. Learning is an important part of autonomy. A system is autonomous to the extent that its behavior is determined by its immediate inputs and past experience, rather than by its designer's.

Furthermore, from the point of view of the evolution of AI, we could summarize that intelligence has three levels.

- The lowest level refers to the systems act as obedient, literal, unimaginative servants which only execute according to the rules already set down for them.
- The second becomes to those can plan for themselves what actions to take in order to satisfy their design objectives, which are assigned by designers in advance.
- The highest intelligence means the systems are able to

determine objectives themselves and can adjust their objectives in response to the change of environment.

With the development of technologies, we require systems in higher degree of intelligence in an increasingly large numbers of applications, among which is the WFM systems.

3.2. Intelligent workflow from AI perspective

It is doubtless that the current WFM systems actualize process automation by supporting the modeling, analysis, and enactment of business process. But from the perspective of AI, the existing WFM systems cannot be regard as intelligent since most of them still rest on, or more strictly speaking, even below the lowest level of intelligence. In WFM systems, every action a computer performs is explicitly anticipated, planned for, and coded by a programmer. If it encounters a situation that its designer did not anticipate, then the result is not usually pretty. Therefore, WFM systems nowadays are far from being intelligent in the sense of AI.

Then what is intelligent workflow management? Intelligent workflow management should have the ability of explicitly describing and understanding the circumstance where the enterprise situates and the purpose of the business process, then determining what activities to undertake and in what sequence according to its experience, and also adjusting and modifying its actions in response to the change of global market. In this case, the processes are not predefined by users, but planned by WFM system automatically to meet the purpose of the business processes based on current environmental conditions. Thus it is easy to carry out the most appropriate process and possible to dynamically modify the process during process execution. Only when it realizes the functions mentioned above could it be called intelligent workflow.

4. A new process of intelligent workflow management

Based on the analysis above, we first give a new process of intelligent workflow management (fig. 2), which is double closed-loop and thus steady and flexible to obtain objectives of organizations. The new architecture of intelligent WFM system provided in next section is according to this new process.

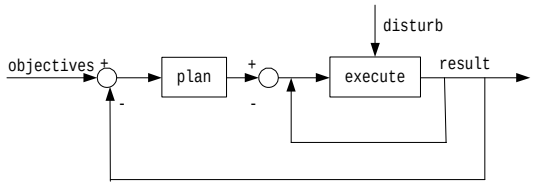

Figure 2: process of intelligent workflow management

Quite different from current workflow management, which has only two phases: build time and run time, the process of intelligent workflow management, as presented in Figure 2, is dynamic and rotative. In contrast to the current system, the input of this new system is objectives users want to achieve, to realize which the system will plan a process automatically. In run time, the system will execute the plan in loop, for disturb from environment may make exceptions and failures to destroy the plan. Nevertheless, this is not enough for sometimes the objectives may change or the current plan cannot realize the primary objectives due to change of environment. As a result, the whole process should be also in such a loop that the plan could be adjusted dynamically according to difference between current states and objectives.

Such a process is both reactive and goal-directed (i.e., proactive). In the architecture that will be provided in the following we will testify the system also has social ability and the ability to learn. Consequently, it satisfies the four properties of intelligent systems. What's more, it can plan for itself, which means it has gone beyond the lowest level of intelligence. In contrast to current system, this new workflow system is not only more capable to deal with those original process or those cannot be described explicitly by people, but more steady and flexible for it is double closed-loop while the former one has no loop at all.

5. Architecture of intelligent WFM system

Figure 3 shows the architecture for such an intelligent WFM system based on the process presented above. Typically it should have seven components:

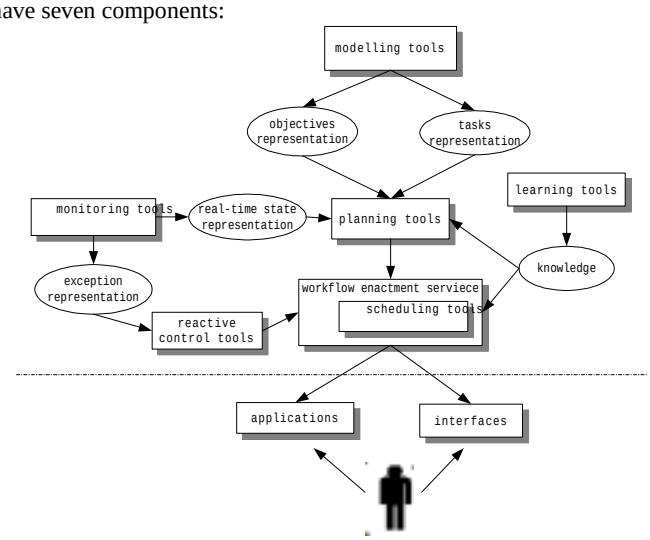

Figure3: architecture for intelligent WFM system

- Modeling tools: In order to allow automatic plan of processes, intelligent workflow management requires two essential models: objectives and tasks. Objectives are expected purpose of process. Basically, the objectives are correlative to the strategy of the enterprise and the market environment. Tasks refer to settled activities in an enterprise. Models of these elementary tasks are generally desirable for constituting more complex processes. Basic constructs that should be recorded for a task include the effects, applicability conditions, resource requirements, scheduling constraints, participants, and involved knowledge. It should also support the definition relating to the time, cost, or quality of performing a task, thus allowing evaluation, comparisons and improvements to be made.
- Planning tools: Planning tools are used to get a best solution to obtain the objectives from current states according to a certain criterion with existing knowledge. When explicit models of objectives and tasks are available, intelligent WFM system can select certain tasks and arrange them in proper order to meet objectives through planning, and thus create a process model automatically. Before the process model is devoted into use, managers can review it and adjust it if necessary. Re-plan in run time is also implemented by this component with current states information provided by monitoring tools.
- Workflow enactment services: This component, the main

part of which is scheduling tools, is similar to current workflow systems. Automatic load balancing and tasking is essential to ensure effectiveness and timeliness.

- Monitoring tools: Intelligent workflow management will require management of processes within highly dynamic and uncertain operating environments. Thus, workflow systems should provide monitoring for critical events and responding appropriately when such events are detected. It provides current states representation for planning tools and exceptions representation for reactive control tools.
- Reactive control tools: When executing the plan, disturb from environment may make exceptions and failures to destroy the plan. In this case, reactive control tools should take certain remedial actions to realize the plan according to exceptions representation provided by monitoring tools. If no actions could be taken to realize the plan, re-plan is inevitable.
- Learning tools: Learning tools are used to attain and discover all kinds of knowledge from experience over time to make other components more intelligent and effective.
- Interaction with human and other agents: Future WFM systems should also be required to work in partnership with others. This includes the ability to negotiate with others.

To conquer the challenges in these seven components are complicated but not absolutely infeasible since we have achieved so much analogical accomplishment in AI field. Technologies excogitated already such as Knowledge Engineering and Representation, Planning, Scheduling, Reactive control, and Machine Learning, can contribute to them. In ensuing section, the potential contributions of these fields are discussed in more detail.

6. AI Technologies contribute to Intelligent WFM systems

The previous section outlined requirements and architecture for an intelligent WFM system. Below, we briefly summarize the roles that technologies of planning, scheduling, reactive control, and machine learning from the AI community can fill within an intelligent WFM system.

6.1. AI Planning

In situations where it is impractical for humans to supply new process definitions, processes must either be created through synthesis of objectives and existing knowledge, or obtained by adapting previously defined processes to meet the new requirements.

Planning is to decide which actions must be taken so that the present state is turned into the goal state when given a set of actions, a goal state, and a present state. Methods from the AI planning community enable composition, adaptation, and synthesis of processes, thus providing the means to expand predefined process libraries to accommodate new situations and requirements. In addition, work on plan repair from this community provides techniques for modifying activated processes in response to execution-time failures and unexpected events.

Among the methods in AI Planning, hierarchical task network (HTN) planning and case-based planning can be used to create new processes in settings where rich libraries of processes are already defined. State-space planners can be used to synthesize new primitive processes for domains where predefined processes are not available[3]. For situations where current processes are inadequate, learning methods may be required to generate new processes that will extend the capabilities of the current set.

6. 2 AI Scheduling

WFM systems require efficient scheduling of activities to processing entities for dynamic and uncertain environments. AI scheduling technology can provide a strong foundation upon which to build such capabilities, including initial task and resource allocation, as well as the ability to adapt and adjust allocations in response to changing requirements and resource availability within WFM systems.

AI scheduling, which is increasingly being viewed as a constraint satisfaction problem, combines rich representations of constraints and powerful constraint reasoning mechanisms with intelligent search techniques. Traditional scheduling algorithms, such as *generative* scheduling and *stochastic* scheduling, while powerful, often failed to address the problem of reactivity when applied in dynamic execution environment. Reactive scheduling has sought to address these problems[3]. Reactive scheduling is motivated by two desires, namely to build schedules that are robust in the face of change, and to produce valid schedules quickly while maintaining stability relative to operations currently underway. The ability to reschedule during execution is an ongoing research problem. Techniques include constraint-directed algorithms and constrained iterative repair.

6.3. Reactive Control

Reactive control systems provide a strong foundation upon which to ground the process activation and management capabilities of a workflow engine. A reactive control system is a form of knowledge-based software controller that operates as an embedded system within highly dynamic environments. Reactive controllers perform actions to accomplish explicitly assigned tasks, while providing real-time response to unexpected events that result from factors that lie beyond the system's control. Such smooth integration of event- and goal-driven activities is an essential component of adaptive workflow management, which must combine task ability with responsiveness to environmental changes.

The development of reactive control technology has been motivated primarily by domains that involve control of computational processes and physical devices (e.g., robots, antennas, satellites, computer networks, software agents). However, many of the techniques and methods can be transferred readily to managing the sorts of processes that have been the focus of the workflow management community. Most relevant to workflow are the *procedural* approaches in which predefined procedure libraries describe processes that can be performed to achieve some goal, or that serve as appropriate responses to designated events[3]. Procedural reactive control is particularly suited for the activity-based paradigm for workflow.

6.4. Machine Learning

Knowledge is the most valuable assets of corporation. WFM system has strong requirement to attain and discover all kinds of knowledge from experience over time to make itself more intelligent and effective thus to provide progressive management of business process.

Machine Learning is the process of knowledge acquisition with the expectation to improve its future performance. The internal behavior of machine learning is to acquire knowledge,

accumulate experience and discover disciplines, while the external behavior is to improve performance and adapt to environment.

There are many sorts of learning methods, including case-based learning, learning through analogy, advice, observation or explanation. The relevant technologies include decision-making tree, deduction and conclusion, clustering, genetic arithmetic, and NN.

Significant stand-alone technologies have been developed in each of the four sub-fields of AI mentioned above. Abiding by the framework mentioned in previous section, integration of state-of-the-art capabilities from planning, scheduling, reactive control, and machine learning would provide an intelligent WFM system relative to current systems, although still lacking in certain dimensions.

7. Conclusion

Intelligent workflow management is the inevitable trend from both perspectives of workflow field and AI field. The process of intelligent workflow management and the architecture of intelligent WFM system given in this paper are totally different with traditional ones, thus they are more adaptive to the new application requirements. The AI communities of planning, scheduling, reactive control, and machine learning have much to contribute to the development of intelligent WFM systems.

Certainly, intelligent WFM systems require more than just a direct integration of state-of-the-art capabilities within these fields. First, advances are required in terms of the capabilities supported by each of the technologies, primarily to support richer process descriptions and improved adaptability. In addition, workflow has special characteristics and requirements that have not been considered in detail by members of these AI communities. Included among these are the need for rich organizational models, security, scalability, and interoperability with legacy systems. Beyond the capabilities of the individual technologies, better integration frameworks are needed that provide richer interoperability of functionality, as required to support adaptability and responsiveness for highly dynamic environments.

To date, there has been only minimal contact between the workflow community and the AI communities. The broader exchange of problems and techniques between these two groups would lead to more rapid development of intelligent systems required to meet the requirements of both commercial and military workflow management applications.

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