Collaborative Multi-agents for Workflow Management*

Huaiqing Wang and Dongming Xu
Department of Information Systems
City University of Hong Kong
Kowloon, Hong Kong
{iswang, isdmxu}@is.cityu.edu.hk

Abstract

Workflow management helps organizations to organize their work on different activities in such a way that the predictable underlying processes are carried out effectively and efficiently in a distributed environment. In this paper, we describe a business workflow management system with intelligent multi-agent support in a collaborative organization environment. With the help from multi-agent collaboration, our workflow management system can organize the organization's work processes and provide resource control, data mediation, semantic mapping, knowledge visualization processing. Such systems are able to manage the organizational workflow more effectively and more efficiently.

Keywords: Intelligent agents, Workflow management systems, Collaboration, Knowledge sharing

1. Introduction

Workflow management helps organizations to organize their work on different activities in such a way that the predictable underlying processes are carried out effectively and efficiently in a distributed environment. A computer based workflow management system (WFMS) organizes the design, execution and monitors general long-lasting business that typically involves multiple activities and multiple collaborating staff in distributed environment. By making the business processes explicit, a WFMS promises to increase the competitive edge of an organization. In this aspect, the coordination of the various activities and the several resources plays a central role [5]. In fact, the business process itself may be seen as a metaphor of different shared resources. The one of the greatest problems in such workflow management is flexibility. How to automate a business process respectively that is constantly changing without costing too much time? How the knowledge and recourse shared efficiently in the workflow processing?

Information and knowledge sharing and collaboration across departments, functions and different information systems within the organization are the key problem to be solved in order to increase organizations' productivity and efficiencies. The backbone of such collaborative organizations is the processing system that holds the enterprise together [15]. In our vision, a Collaborative Organization Environment (COE) with intelligent multi-agent support is the backbone to handle such tasks. Our COE is a collaboration infrastructure that allows the multi-agents to communicate each other to share their knowledge and resources, regardless of their different geographic locations, and to help the organization for the decision making, and for the development of better products, faster and cheaper than ever before.

In this paper, we describe a business workflow management system with intelligent multi-agent support in a particular Collaborative Organization Environment. Thus, our system consists of a number of agents, which operate autonomously and cooperatively with each other to perform the tasks in the WFMS and to distribute knowledge, recourses and strategies across the individual departments.

Formally, the term agent is used to denote a software-based computer system that enjoys the

* This research is supported by research grants (No.7000840 and 7100109) from the City University of Hong Kong.

following properties [13]. Basic agent functions are the execution of assigned subtasks and the communication with other agents. Intelligent agents enjoy the following properties [12].
Autonomy: Agents operate without the direct intervention of humans;
Co-operativity: Agents co-operate with other agents towards the achievement of certain objectives;
Reactivity: Agents perceive their environment and respond in a timely fashion to changes that occur;
Pro-activity: Agents do not simply act in response to their environment; they are able to exhibit goal-directed behaviors by taking the initiative;
Mobility: Agents are able to travel through computer networks. An agent on one computer may create another agent on another computer for execution. Agents may also transport from computer to computer during execution and may carry accumulated knowledge and data with them.

Furthermore, from our research, the workflow management system with such intelligent agents support has the following novel features:

- Storing organizational and individual knowledge and giving guidance timely.
- Branching and looping conditions of dependents and iterative processes simultaneous.
- Allowing changes to the workflow during execution.
- Achieving individual and shared goals of the participants.
- Collaborating and co-operating with each other within the organization.

2. Workflow Management with Multi-Agent Support

Workflow refers to group activity automation by task sequencing and information routing [10]. Workflow describes the processes of an enterprise on a lower level with focus on the execution of the processes [14]. Thus, workflow is a collection of tasks organized to accomplish some business processes. An activity can by perform by one or more software systems, one or a team of humans, or a combination of these [11]. This definition related the workflow concept to automating the information part of business processes. Workflow management involves the (re) design and the (re) implementation of workflows as the needs and the goals of an enterprise change.

Based on the study above, we propose a business workflow management system with intelligent multi-agents support in a Collaborative Organization Environment. The architecture of our system is shown in figure 1. The proposed system consists of a number of agents, which operate autonomously and cooperate with each other to perform their tasks. The collaboration among agents is of the major concern for achieving the goal of the system.

At the top level in the figure 1, i.e. at the organization workflow level, the information, knowledge and recourses are shared within the system to help the organization for the problem-solving, dynamic learning, strategic planning and decision-making. Each component can receive the information and knowledge from both external and internal, e.g. from the Marketing Department. And the information can be shared between or among the different components while the workflow processes. The lower level, i.e. the collaborative agents environment, is a network of cooperating agents that perform one or more workflow functions. Each agent coordinates its actions with other agents. The workflow tasks are organized in the collaboration multi-agents environment to achieving organization's goals.

In our architecture, the intelligent multi-agents can be classified into three sub-classes in term of their capabilities, functions and their mental states, which includes the representation of their beliefs and their commitments (see figure 2):

- Generic Agents (shown as circle icons with shadow) perform generic functions, such as information searching, receiving, filtering and distributing, e.g. Knowledge Filtering Agent, Distributing Agent and Diagnostic Agent.
- Domain-Specific Agents (shown as rounded rectangular icons with/without shadow) work in virtual workspace to

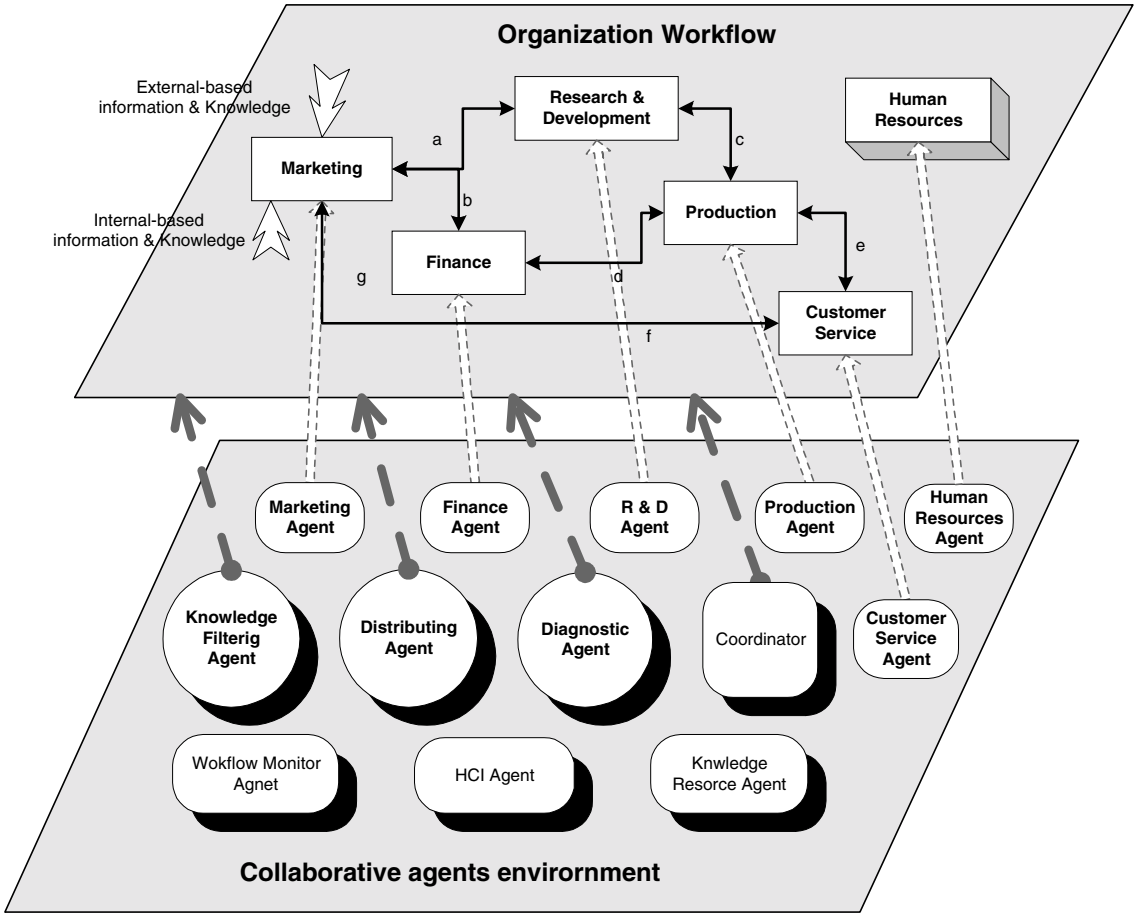

Figure1. Diagram of Collaborative Organization Workflow Management

represent the individual component in the organization workflow. For instance. A User Agent represents a particular user. An HCI Agent represents the human computer interface capabilities between organization and network.

- The Coordinator Agent (shown as rounded square icon with shadow) manages all of the other agents, as well as supports system operation

All of these intelligent agents work and react depending on their internal states, goals and believes. The agents do not only pass service requests and reply with information, but also deliver their knowledge in some specific format. Therefore, they should have a common shared communication protocol among them so that they can understand each other freely, collect knowledge from others and interact with other agents continually.

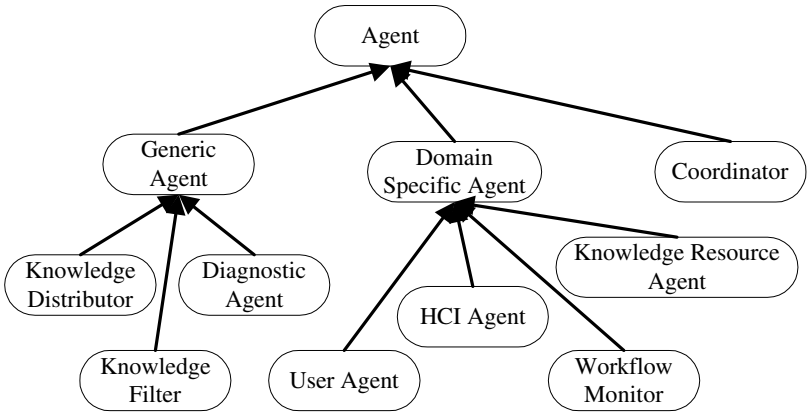

Figure 2: The Agent hierarchy

3. Intelligent Agents

The concept of intelligent agents is rapidly becoming an important area of research [3], [4], [6]. Informally, intelligent agents can be seen as software agents with intelligent behavior, that is, they are the combination of software agents and intelligent systems. Various research has been conducted into applying intelligent agent based technology towards real world problems, including SoftBot [4], a project aimed at autonomously performing predefined general Internet tasks, developed at University of Washington by O. Etzioni, and Maxims [4], an intelligent user assistant for information filtering, as developed by P. Maes at MIT MediaLab. More specifically, for example, "Softbot" (Software Robot) uses a UNIX shell and the World Wide Web to interact with a wide range of Internet resources. The Softbot agent provides an integrated interface to the Internet, dynamically chooses which facilities to invoke, and fluidly backtracks from one facility to another based on information collected at run time. Furthermore, there has been a rapid growth in attention paid to developing and deploying intelligent agent based systems to tackle real world problems by taking advantage of the intelligent, autonomous and active nature of this technology.

The communication between agents is considered a sequence of communication and computation steps[2]. The communication capabilities of the mediator agent are generating and sending message t other mediator agents and the local domain agent, as well as receiving and decoding messages from other mediator agents and the local domain agent, incorporating beliefs, commitments and information from those other agents in the network. However, agents are developed from a template design that consists of five individual layers [8]: transport (agent message transport), message (agent communication), protocal (conversation policies), agent (basic agent components, such problem solvers), and detailed agent (domain-specific or agent specific tasks).

A novel model of an agent, which consists of four main components, is shown in the left part of Figure 3. The model specifies agent behavior and its interactions with other agents and system. The communication interface component manages the communication between the agent and the outside world. The communication is message-based, and uses a simple and extensible language for communication among agents. The operation facilities component is the central control and action part of an agent. It holds to sub-components called Transaction Engine and Coordination Mechanism respectively. The Transaction Engine is the generic execution engine that can execute different functions such as a Graphic User Interface (GUI) and an inference machine. The available functions are stored in the Repository component as function models, which can be changed from time to time.

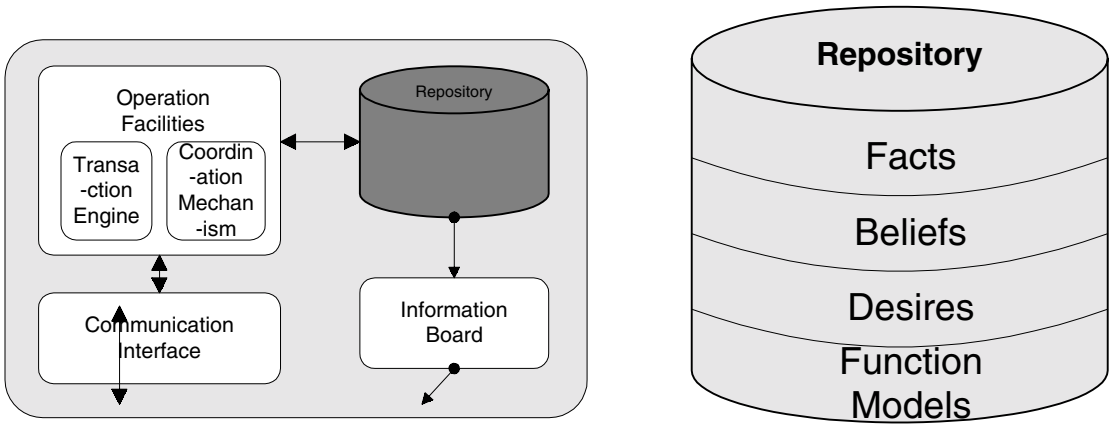

Figure 3. The Agent Architecture and its Repository

The Coordination Mechanism sub-component is responsible for the coordination with other agents. The detail coordination mechanism will be mentioned a little bit later. The Information Board component is the place, where other agents can get the really ability and the public beliefs of this agent. It is very important to know who can supply the desired function when an agent needs help.

The Repository component is shown in detail in the right part of Figure 5. It stores the Facts, Beliefs, Desires and Function Models of an agent. Facts are simply beliefs about the agent and the environment in which the agent has complete confidence. Facts or beliefs may be held privately or publicly. Desires represent the goals, preferences that motivate agent and the commitment of the agent that is about to actually perform some set of intended actions. The Function Models are the services that an agent can provide. When an agent is required by another agent to supply some services, the Operation Facilities will pick up the suitable function model from Repository component and then let the Transaction Engine execute it.

Intelligent agents work together autonomously and cooperate with each other to perform the tasks in the Organization Workflow system appropriately. The following describe these agents in details.

Distributing Agent retrieves and gathers the relevant information and knowledge from a variety of dispersed internal and external resources, and distributes the results to the other agents in the workflow management system.

Knowledge Filtering Agent filters un-useful messages. This can be done at the sender's side according to his privacy needs, at the receiver's side according to his interests, or at the organizational level according to basic company policies.

Diagnostic Agent attempts to generate a causal explanation when some emergent situations happen.

Workflow Monitor Agent tracks and monitors the status of all agents and operation of workflow processing. For managing such WFMS running efficiently and effectively, this agent tracks the knowledge flow and measures the WFMS successfulness.

HCI Agent provides the interaction between users and the WFMS.

Knowledge Resource Agent reasons about capabilities of, and relationship between, organizations resources. This agent is responsible for keeping track of resources in the dynamic environment. i.e. Resources may be changed, moved to different locations or even disappear at anytime.

User Agent represents individual component in the organization, e.g. the Marketing Agent, to accomplish the user's goals in the organization.

Coordinator is an agent that is required to manage all of the other agents, as well as support the system operation.

4.Knowledge Level Collaboration with Agents

Communication, collaboration and coordination are the different layers of view of interaction. Communication allows participants in the decision process to share information (this

involves networking infrastructures), collaboration allows participants to collaboratively update some shared set of decisions (this involves support for tele-conferencing etc.) and coordination ensures the collaborative actions of the individuals working on a shared set of decisions are coordinated to achieve the desired result efficiently [7]. Each layer is built on the top of the next layer. So, collaboration means more than just instantaneous communication, or total asset visibility or leveraging resources and the talents of experts from different fields. Collaboration means all of that, and more. Another concept of collaboration entails a situation where everyone is a potential equal contributor to a discussion transcript that becomes important as a memory for that group. Ideally such a transcript can evolve to become a knowledge base for the collaborators and those who use the results of the discussions [11].

Collaboration involves creativity, innovation and decision-making. Unfortunately, it also involves looking for files, locating and scheduling resources and populating databases. Automated collaboration lets the human collaborations do what they do best think, create, and decide-and lets the computers take care of the data and resource management. A complete collaboration environment has all the components necessary to ensure that knowledge can be shared and used at the moments when it can best impact the product. The term of "collaboration" is used to a set of participants working together to produce a product or service. Collaboration requires two or more participants who contribute to a common task. A crucial point for successful collaboration is the manner in which individual work is related to the group as a whole. Co-workers make autonomous decisions when working alone, under changing and unpredictable conditions, which the group cannot foresee or plan for. To enable a separated group of co-workers to collaborate, they need to coordinate themselves. The importance of coordination can be seen in the need to bring the efforts of all co-workers together in order to produce a product or service.

The goal of our collaborative environment is the need to transform the organization's data into information that the enterprise can apply to their product and processes that will generate the knowledge required to improve the design and realize the goal-the product and service. Collaborative work is necessary in situations where unpredictable work pattern make it difficult to deploy standard workflow management systems.

With the Collaboration Multi-agent Environment, collaboration goes beyond the simple, serial exchange of information between varied disciplines or domains. Members of collaboration, known to our Organization Workflow System as different kinds of agents, need robust, access to all the available information about the product and the development process, and the resources to use that information. They need decision support, knowledge management and the virtual environment to hold the collaboration together. Our collaborative multi-agent environment provides the application independent framework to meet the infrastructure needs of everyone involved in collaboration. However, our system applies state-of-the-art multi-agent technology to provide the communication, visibility and resources to capture and harness the true power of collaboration-knowledge. And, it takes the next step, by providing that knowledge to the people who need it, in a form they can use, giving them the decision support they need to move the enterprise closer to its goal.

5. An Example

In order to evaluate the effectiveness of our COE, in terms of workflow management, a new product problem domain is used to demonstrate how to deal with multiple agent collaboration.

Assume that there are four departments in an organization, Marketing Department, R & D Department, Finance Department, and Production Department, which are involved in a new product development (see figure 4). The Marketing Department initializes the requirements from users and raises a proposal to produce a new product. This proposal will be passed to the R&D Department for research and prototype development and to the Finance Department for budget and cost estimation. After both departments complete their tasks, the Production Department will start to produce it. A number of corresponding agents in our COE

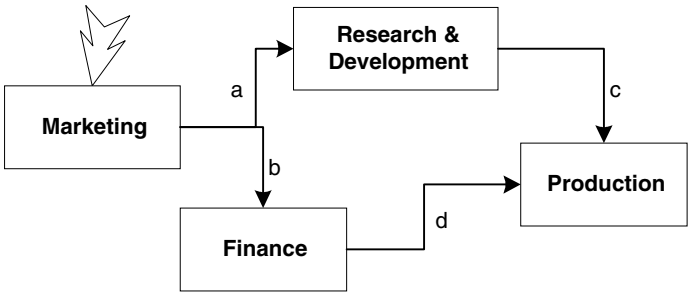

Figure 4: A Portion of the Organizational Workflow

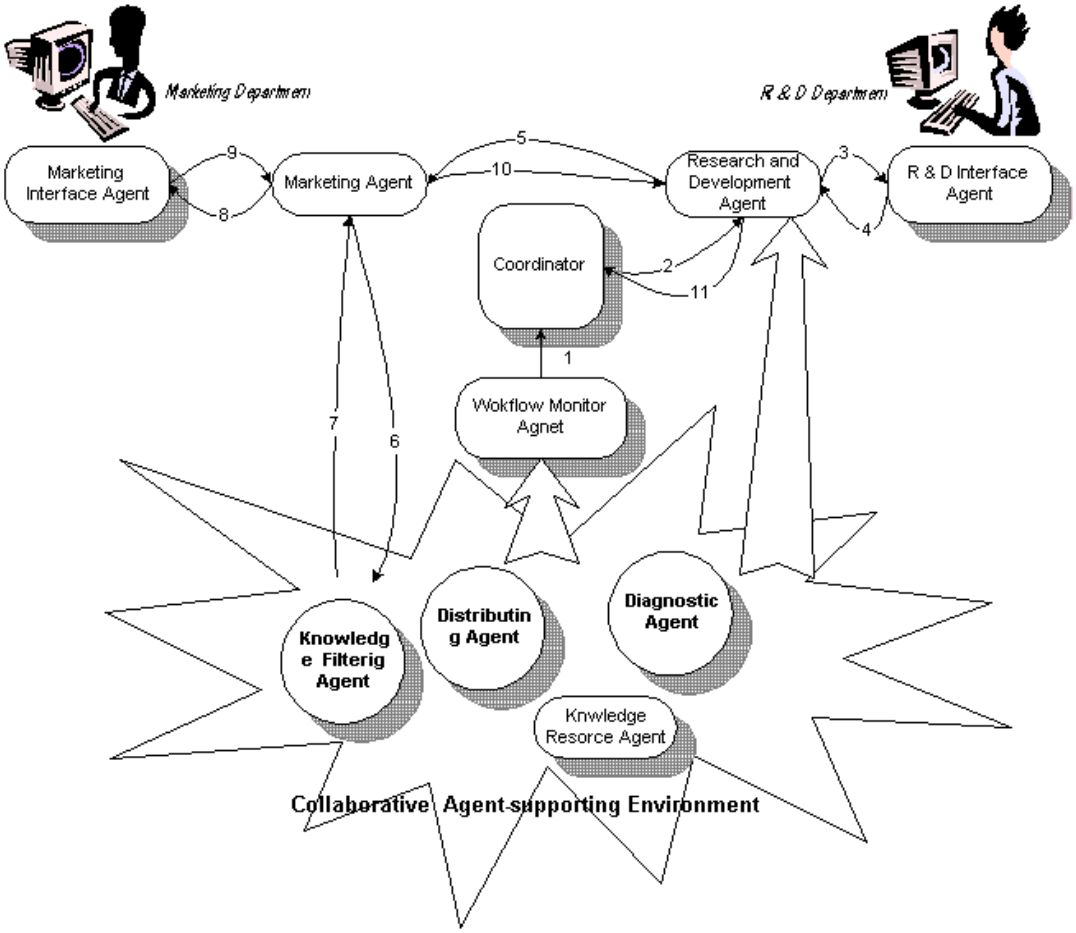

Figure 5. COE workflow management of Case 1

can support regular workflow management activities. Such intelligent agents can work cooperatively to solve more complicated problems.

Case 1 (shown as figure 5): Assume that the R&D Department has problems to complete their R&D task on time. When reaching the dead line, the Workflow Monitor agent will find this problem and will report this event to the Coordinator agent (step 1). Upon receiving such notice, the Coordinator agent will send a query to the R&D agent to investigate this matter. The human manager of R & D receives such information through R & D Interface Agent (step 3). Assume that such delay is caused by one of the user's requirements is too high and the R&D

Department cannot reach such requirement. The R&D agent will receive such information from R & D Interface agent through the interaction between that manager and computer (step 4) and pass that information to the Marketing agent for negotiation (step 5). The Marketing agent will ask the Knowledge Resource Agent for the relevant knowledge and get the results after the collaborative work around those agents, e.g. Knowledge Filtering Agent, Diagnostic Agent, Distribution Agent and Knowledge Resource Agent, which in the COE (step 6 and 7). Then it will ask and get the results from the Marketing Department for relaxing the requirement through the interaction between the manager of marketing department and computer by Marketing Interface Agent (step 8 and 9). Assume that such requirement can be relaxed, the Marketing agent will pass such new-relaxed requirement to the R&D agent (step 10) and the Finance agent. This collaborative process may happen several times until this issue solved. Then, the R & D Agent will send Coordinator the final report (step 11). The example above demonstrates that the problem has been solved by the collaboration among a number of agents in COE.

Case 2: Assume that the Finance Department finds that the cost of the new product is too high. They issue such problem to the Finance agent for investigation. The Finance agent will send a query to the R&D agent. The R&D agent will collect necessary information and present such information to the R&D Department. The R&D Department will analyze such information and discuss how to reduce the cost. They will propose a number of options to other Departments through agents. After several rounds of negotiation, a modified plan will be proposed.

From the two cases above, it is clear that our COE can provide re-active and pro-active services for workflow management, under the help of multi-agent collaboration.

6. Conclusion

It is increasingly recognized that organizations need to develop better systems to manage their workflow. In particular, workflow across departments, functions and geographical location is discussed as a core organizational competence for many (if not all) organizations [1]. Similarly, business processes can be subjected to workflow techniques, such as claims processing within an insurance company or order processing, inventory, and stock management. A standard-based collaboration environment provides an environment by multi-agents technology to share organizations' knowledge and resources, regardless of the geographic location of the individual end user, and to help the organization for the decision making, knowledge management and shared recourse to develop better products, faster and cheaper than ever before.

In this paper, we have presented a number of research issues, *workflow management, knowledge collaboration, intelligent multi-agents* and *multi-agent's classification*. We have also proposed an intelligent agent based novel architecture and a collaborative organization environment, which takes advantages of the intelligent, autonomous and active aspects of intelligent agent technology. In particular, this architecture has the following novel features:

- Successful integration of collaboration into a workflow management system by the means of applying intelligent agent technology. Under our system, three distinct subclasses of intelligent agents have been identified. Generic Agents are designed for generic functions. Domain-Specific Agents work in the virtual workspace to represent the individual component in the organization workflow. The Coordinator Agent supports inter-agent communication and system operation.
- Workflow is responsible for tracking, automating and management of business process. Our system can be used for automating existing processes, or as a planning and implementation tool for Business Process Reengineering.
- The active agents can understand the intentions and objectives of particular users or components and act on his/her behalf. The collaboration between agents will be able to help the end users to analyze, understand and interact cooperatively in the business process, and to overcome information overload.
- Recourses are used extensively and flexibly. Usually, most resources are never intended to be used by others. Our system uses multiple intelligent agent technology to provide resource

control, data mediation, semantic mapping, knowledge visualization processing, and a host of other capabilities to integrate resources into a collaborative environment.

References

[1] Newell, S. and Scarbrough, H., " Intranets and Knowledge Management: Complex process and Ironic Outcomes", proceedings of the 32nd Annual Hawaii International Conference on Systems Sciences, 5-8 Jan. 1999. on pp.10.

[2] Barbuceanu, M. and Fox, M.S., " Coordinating Multiple Agents in the Supply Chain", proceedings of the 5th Workshop on Enabling Technologies, 19-21 June 1996, pp. 134-141.

[3] Bhargava, H. K., and Branley Jr. W. C., (1995) "Simulating belief systems of autonomous agents", Decision Support Systems, 1995, Vol. 14, pp 329-348.

[4] Etzioni, O., and Weld, D., "A Softbot-based Interface to Internet", Communications of the ACM, July 1994, Vol. 37, No. 7, pp. 72 - 76

[5] Kappel, Gerti; Rausch-Schott, Stefan & Retschitzegger, Werner, "Workflow and Coordination", Coordination Technology for Collaborative Application, 1998, pp. 99-120.

[6] Khoong, CM, "Decision Support System: An Extended Research Agenda", Omega, 1995, Vol. 23, No. 2, pp. 221-229.

[7] Klein, Mark, "Coordination Science: Challenges and Directions", Coordination Technology for Collaborative Applications, 1998, pp161-176.

[8] Pancerella, Carman and Berry, Nina M., "Adding Intelligent Agents to Existing EI Frameworks", IEEE Manufacturing, September/October 1999, pp. 60-61.

[9] Schmidt, Gunter, "Scheduling Models for Workflow Management", Business Process Modeling, 1996, pp.67-80.

[10] Takeda, K.; Inaba,M. & Sugiara, K., "User Interface and Agent Prototyping for Flexible Working", IEEE Multimedia, Summer 1996, Vol. 3, pp. 40-50.

[11] Turoff, M.; Hiltz, S.R.; Bieber, M.; Fjermestad, J. and Rana, A., "Collaborative Discourse Structures in Computer Mediated Group Communications", proceedings of the 32nd Annual Hawaii International Conference on Systems Sciences, 5-8 Jan. 1999, pp. 9.

[12] Wang, Huaiqing, "Intelligent Agent Assisted Decision Support Systems: Integration of Knowledge Discovery, Knowledge Analysis, and Group Decision Support", Expert Systems with Applications, 1997, Vol. 12, No. 3, pp.323-335.

[13] Wooldridge, M. And Jennings, N., (1995) "Intelligent agents: theory and practice", The Knowledge Engineering Review, 1995, Vol. 10, No. 2, pp. 115-152.

[14] Zukunft, Olaf and Rump, Frank, "From Business Process Modelling to Workflow Management: An Integrated Approach", Business Process Modelling, 1996, pp.3-22.

[15] http://www.ballcee.com/, 2000 Ball Aerospace & Technologies Corp.