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Petri Nets Based Coordination Component for CSCW Environment

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In view of the lack of efficient coordination of interdependent task in the collaborative design system, the mechanisms for temporal and resource coordination problems are established based on Petri Nets, respectively. Both of the mechanisms are encapsulated and implemented in the coordination component so as to increase the flexibility and acceptability of the system. We model the CSCW system based on Petri Nets for simulation, analysis and optimization. A case study on the overhead traveling crane is given to demonstrate and validate our theory.

Key Words : CSCW, Coordination Mechanism, Temporal Interdependencies, Resource Management, Coordination Component

1. Introduction

With the fast development of computer techn ology and Internet, we have witnessed the rapid establishment of virtual society and realized the feasibility of remote interaction transcending the geographic location and time constraint. It is necessary to design complex artifacts and systems that facilitate the cooperation of multidisciplinary design teams using multiple sophisticated commercial and non-commercial engineering tools such as CAD tools, modeling, simulation and optimization software, engineering databases, and knowledge-based systems. This has been viewed by researchers and industry engineers as the key for reducing cycle times and improving product quality and reliability (Monplaisir, 1999 ; Kan et al., 2001).

The specialists and scholars from the entire world have designed and developed many models or environments to meet the requirements mentioned above. Wang and Zhang (2002) introduced a CAD and CAM integrated system to shorten the product development cycle to the greatest degree and rapidly respond to the unceasingly changing market requirement. Benford et al. (1997) established a model based on VE (Virtual Environment), Java, etc technologies to access, explore and collaborative through the Internet. These models or environments have met the requirements and improved the efficiency of design and development in a certain extent. But none of them is efficient enough to coordinate the interdependent tasks in the large system.

Shirmohammadi and Georganas presented an architecture that support tightly coupled collaborative tasks to be performed efficiently in the design system (Shirmohammadi and Georganas, 2001). But the rigidity of the collaborative protocols restricts its ability of collaboration in complex system.

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In this paper, we establish the coordination mechanisms for temporal and resource interdependencies respectively, and encapsulate the two kind of mechanisms into the coordination components for collaborative design and development system. The rest of the paper is organized as follows. Related works and concepts are reviewed in Section 2. Coordination mechanisms for the temporal and resource dependencies and coordination components based on Petri Nets in a three-level scheme are introduced and explained in Section 3 and 4, respectively. The development of overhead traveling crane is described in Section 5 to demonstrate the proposed method. Conclusions and future works are presented in Section 6.

2. Related Work

2.1 Designin

The process of design is an act that involves members of many professions. Collaborative design is that teams of designers, engineers and manufacturers from several areas and diverse geographical locations work together over networks (Kvan, 2000; Xu and Liu, 2003; Park et al., 2004).

There are two representative activities in collaborative design and different coordination mechanisms correspondingly. One kind of activity is "loosely coupled collaborative design," as shown in Fig. 1. It could be well coordinated by a social protocol and participant's abilities even without any explicit coordination mechanism.

The other activity called "tightly (close) coupled collaborative design" is given in Fig. 2. In this kind of activity, tasks depend on one another. E.g., one task can be started only after some other tasks are started, being executed or finished During the process of collaborative design, each participant hopes every interdependency task succeed and every other partner succeed too. However, they are not always harmonious. So there must be coordination between these interdependency tasks to ensure the whole systems execute successfully (Raposo et al., 2001).

2.2 CSCW

In collaborative design systems, individuals or individual groups of multidisciplinary design teams usually work in parallel and separately with various engineering tools, which are located on different sites, often for quite a long time. At any moment, individual members may be working on different versions of a design or viewing the design from various perspectives, at different levels of details. Computer supported cooperative work (CSCW) system offers a tool that could potentially enhance the productivity and effectiveness of teams. The primary goals of applying CSCW technology include cost reduction, space optimization, improved performance, effectiveness and satisfaction. There are also more specific goals, such as improving group cohesiveness and diminishing the influence of dominant figures (Monplaisir, 1999; Kamel and Davison, 1998).

2.3 Component

A component is a reusable software package or application. A standard application has two main

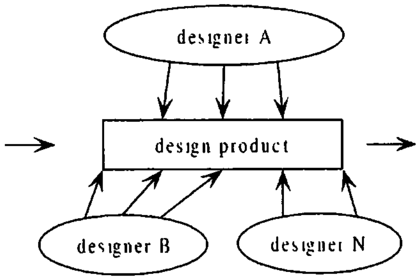

Fig. 1 Loosely coupled collaborative design

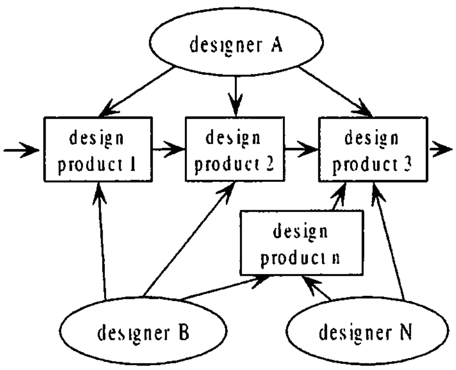

Fig. 2 Tightly coupled collaborative design

parts, the implementation and the data. The interaction between two applications is through the database. In fact this interaction is limited to the data sharing. A component-based application provides operation services containing the data operation and method operations in its implementation (Rosenman and Wang, 2001).

Cockburn, et al.(1995) examine and record the major causes of component failure, and provide four principles of component design to encapsulate the problems and guide the designers. The four principles are maximization personnel acceptance, minimization requirement, minimization constraints and external integration. This is the basic principles for establishing all kind of components (Cockburn and Jones, 1995).

3. Coordination Mechanisms

The design and development of a product involve many tasks and these tasks could be decomposed into many subtasks (Park et al., 2002). We can classify these tasks into two main classes, independent and interdependent. Independent task has no or little relation with others and therefore can be implemented separately. Experience tells us that most tasks belong to the latter which interact with others in one or several aspects. Interdependencies are divided into two types, temporal and resource dependencies (Ricarte et al., 2002; Raposo et al., 2001).

3.1 Temporal dependencies

Temporal dependencies establish the execute order for the tasks. Fig. 3 shows the temporal dependencies between two tasks (Raposo et al., 2001).

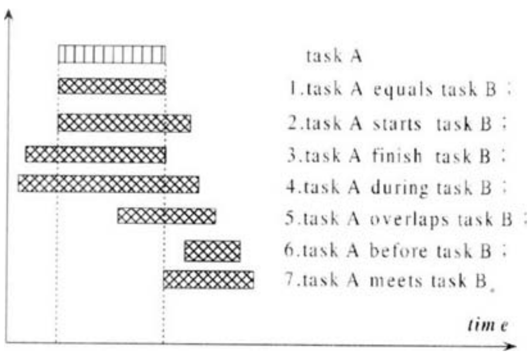

Fig. 3 Temporal interdependencies

1) Task A equals task B: Task A and task B start together and have the same time interval.

2) Task A starts task B: Task A and task B start together, but have the different time interval.

3) Task A finishes task B: Task A and task B finish together, and have the different time interval.

4) Task A during task B: Task A is totally contained in task B.

5) Task A overlaps task B: Task A starts before task B, which starts before the end of Task A.

6) Task A before task B: Task A happens before task B, and they do not overlap.

7) Task A meets task B: Task A happens before task B, which starts immediately after the end of Task A.

These conditions include the possibilities that may happen between two tasks. What we could do is to establish corresponding mechanisms to coordinate these dependencies.

3.2 Resource management

The resources needed for tasks are managed by one or more resource managers. Resource managers control the allocation of resources to tasks. Resource management interdependencies are complementary to temporal ones and may be used in parallel to them. This kind of interdependency deals with the distribution of resources among tasks. Three basic resource management dependencies have been defined (Raposo et al., 2001).

Sharing: A limited number of resources may be shared among several tasks. It represents a common situation that occurs, for example, when several designers edit a product drawing.

Simultaneity: A resource is available only if a certain number of tasks request it simultaneously. It represents, for instance, a machine that may only be used with more than one operator.

Volatility: Indicates whether, after its use, the resource is available again. For example, a printer is a non-volatile resource, which a sheet of paper is volatile.

3.3 Coordination mechanisms

In this context, the coordination is defined as the act of managing interdependencies tasks performed to achieve a goal. The coordination is a highly dynamic process because of the renegotiation during a collaborative effort. Without the coordination mechanisms, the participant may get involved in conflicting or repetitive tasks (Raposo et al., 2000). One coordination mechanism only can solve one kind of corresponding problem, so in large systems for designing complex products, many coordination mechanisms need to be established to solve different kinds of potential problems.

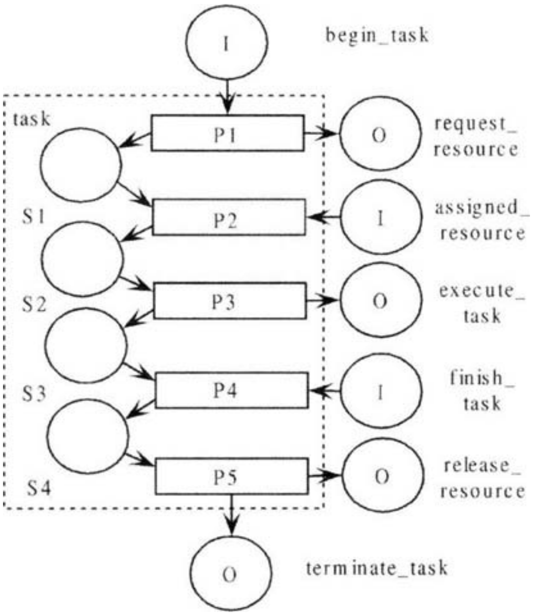

Fig. 4 Structure of task (van der Aalst et al., 1994)

The coordination mechanisms modeled for the temporal and resource management are based on the classical Petri Nets. Fig. 4 shows the structure of a task which is based on Petri Nets and Fig. 5 shows the structure of resource manager [van der Aalst et al., 1994]. As shown in Fig.4, each task has a dependency on another task with five transitions (P1, P2, P3, P4 and P5) and four places (S1, S2, S3 and S4). The places *request_resource*, *assigned_resource* and *release_resource* connect the task with resource manager. The places *execute_task* and *finish_task* connect the task with the temporal coordination mechanisms. Consequently both the temporal and resource interdependencies are coordinated.

The proposed coordination environment includes three distinct hierarchical levels, workflow, coordination and execution (van der Aalst et al., 1994). The whole system is delineated at the workflow level. All tasks are assigned to different participants, at the same time, temporal and resource interdependencies between the tasks and participants are established. Under the workflow is coordination level where the interdependent tasks are coordinated by the coordination components. All tasks of the system are actually executed at the execution level.

4. Coordination Component

Figure 6 shows the components involved in the

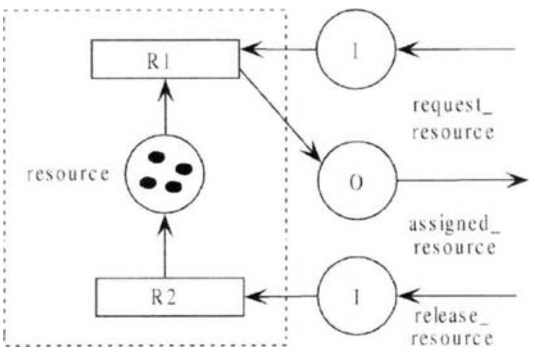

Fig. 5 Structure of resource manager (van der Aalst et al., 1994)

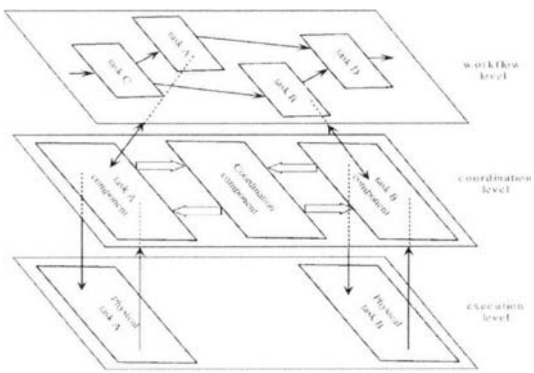

Fig. 6 Three levels of collaborative design system

coordination interdependencies between the two tasks in the three-level scheme. At the coordination level, there are three components, a coordination component and two task components. The two task components represent task A and task B respectively and maintain the task's schedule. The coordination components implement the modeled coordination mechanisms, both for temporal and resource management dependencies.

In order to coordinate temporal relations as shown in Fig. 3, several coordination mechanisms are established. Fig. 7 presents the model of coordination mechanism for the temporal relation of task A equals task B. Between task A and task B

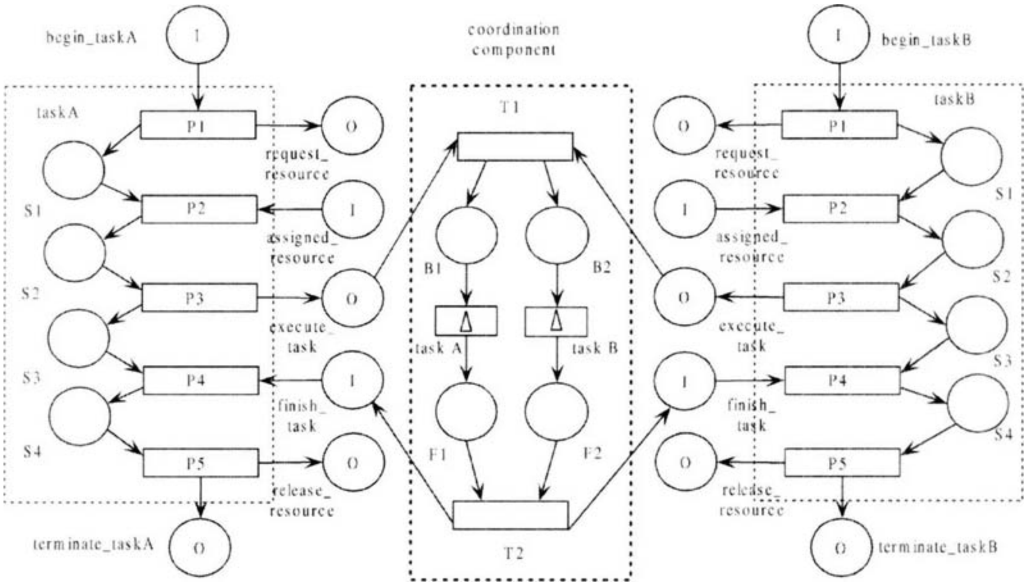

Fig. 7 Coordination mechanisms for task A equals task B

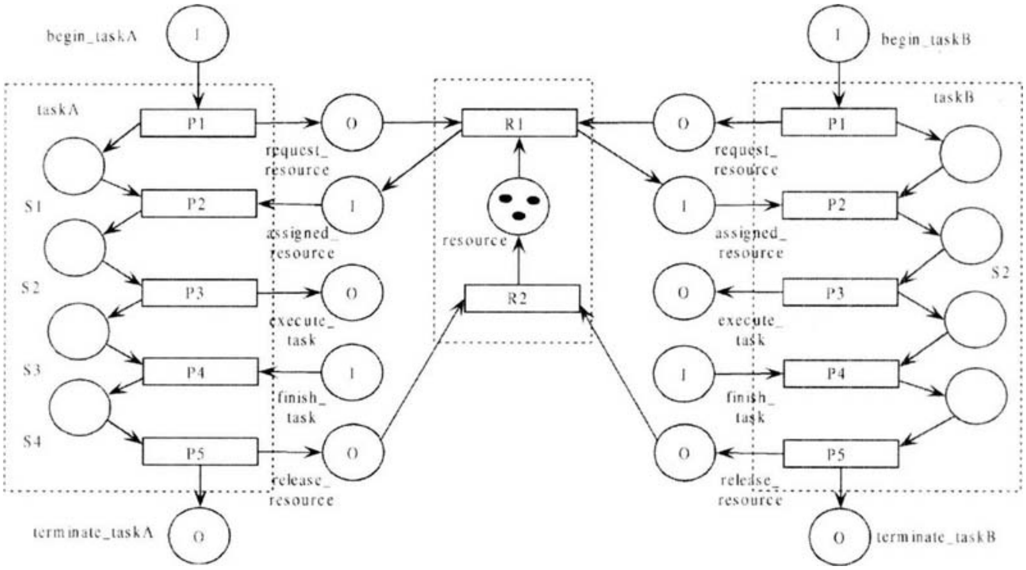

Fig. 8 Resource manager for two tasks sharing resources

is temporal coordination component which ensures the simultaneity of the beginning and finishing of task A and task B. Transition T1 ensures the simultaneous beginning of the two tasks and transition T2 ensures the simultaneous finishing. Transitions task A and task B in the coordination component are non-instantaneous transitions. This represents the actual execution of the two tasks in the execution level. Different coordination mechanisms are also established to coordinate respective interdependencies as shown in the Fig. 3.

In Fig. 8, between the two tasks is the resource coordination component which manages the resources between task A and task B. This figure shows sharing, one of the basic resource dependency defined above. The place resource contains three tokens which represent the available resources. According to conditions of the input places *request_resource* and resource, transition R1 will determine whether to assign the corresponding resources to the task which has send the request. Transition R2 reclaims the resources which have been released.

In design and development of the system, the coordination component was established to coordinate the interdependency tasks. Temporal and resource coordination mechanisms, as two main mechanisms of the coordination component, were encapsulated into the component to implement their functions. As shown in Fig. 9, besides the interaction between the coordination and tasks, there are interactions between these two mechanisms to ensure the component's efficiency.

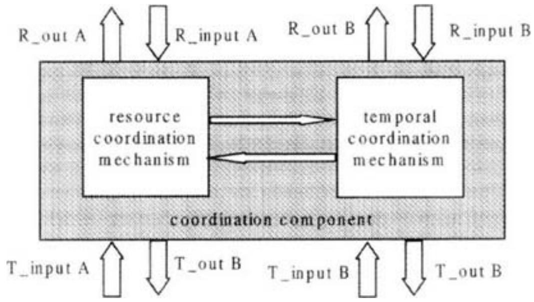

Fig. 9 Functioning of coordination component

5. Applications

As we all know, the development of crane is a complexity process. This work needs the cooperation of the experts and engineers from different fields and departments. Fig. 10 shows the struc-

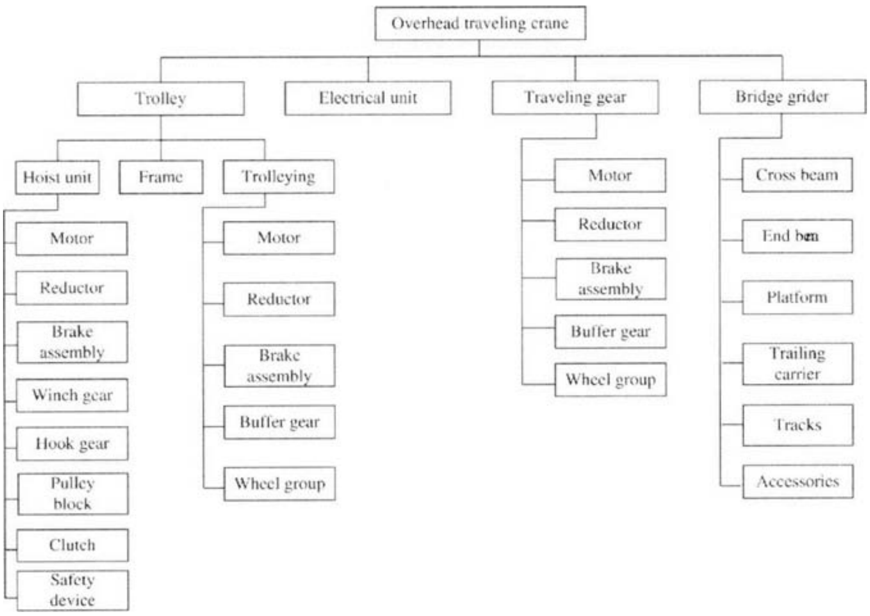

Fig. 10 Structure decomposition of traditional overhead traveling crane

ture decomposition of traditional overhead traveling crane. Generally, design phase could be decomposed into three phases : conceptual design, technical design and working design. To model the collaborative design system, we have to describe the designing process of parts or assemblies in detail, it would be a very complicated work considering the dimensional and functional interactions between them. For example, dimensions of the Cross-beam and End-beam will affect the structure, dimensions and selection of some parts and assemblies, such as frame of trolley, platform, trailing carrier, track, wheel groups, winch gear and etc.

To coordinate the interdependencies tasks of the design, we establish the collaborative design system based on Petri Nets, as shown in Fig. 11. During the build-time, we build the flow diagram of the design development by task components and resources components according to their interdependencies. Process manager controls the execution of tasks in the diagram and resource manager manages the access of the resources of the system. Then coordination component ensures the execution of system during the run-time. Clients could monitor the whole process of the development of crane through the interfaces of the system.

Compared with the traditional design system, our model has several advantages as followed :

(1) Increase flexibility and acceptability. The change of the problem will lead to little change of the model compared with traditional model. The model is easier to understood and used by different levels of users.

(2) Convenient for mining and reuse. Components can be safely reused by any other systems.

(3) Easy of run-time maintenance. The modeling mechanisms make it very easy for the designers to localize the system errors.

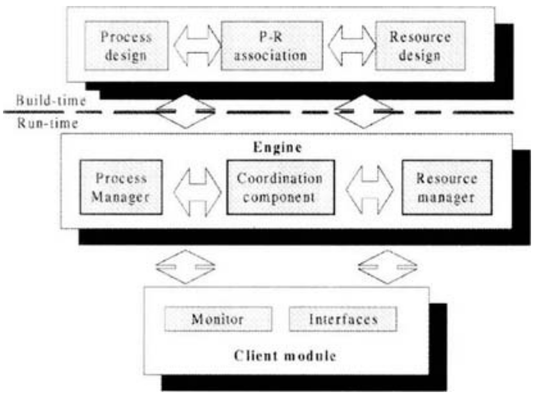

Fig. 11 Architecture of the collaborative design system

6. Conclusions

In this paper we have presented an approach for tasks coordination in CSCW system. Coordination mechanisms for temporal and resource interdependencies were established respectively. Theories of Petri Nets and components are introduced to modeling the collaborative design system for simulation, analysis and optimization. Therefore some potential problems in the system could be found in advance. And the construction of coordination component makes the coordination in a modular and pluggable way and the whole system has more flexibility and acceptability.

In the future, we will consummate the mechanisms to improve the ability of coordination, and at the same time improve the computing ability of CSCW system to reduce the chance of deadlocks. Furthermore, model based on Petri Nets for workflow mining is one of our future works.

Acknowledgments

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