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ONTOLOGIES TO SUPPORT THE MANAGEMENT OF NEW PRODUCT DEVELOPMENT IN THE CHEMICAL PROCESS INDUSTRIES

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1 Introduction

The effective management of the new product development (NPD) process is essential for the survival of a business in today's marketplace. NPD typically involves a number of disciplines. It also takes place in a context of competing requirements and influences—e.g. short time-to-market vs. high quality of product—which have led to the introduction of concurrent and collaborative engineering techniques [7]. Because of its interdisciplinary nature and these competing influences, NPD processes within a business are difficult to manage and co-ordinate. Research suggests that poor management of the process—such as lack of communication and inappropriate cutting of corners—contributes to many failures of new products [2]. Workflow management systems are widely used for the streamlined management of "administrative" processes, but current systems are unable to cope with the more dynamic situations encountered in ad-hoc and collaborative processes [1]. It is this class of dynamic, collaborative processes which encompasses most engineering activities, and hence there is increasing interest in the use of knowledge-based techniques to provide more flexible process management support in such areas [4].

2 Objectives and Approach

The TBPM (Task-Based Process Management) project is investigating the provision of intelligent support for the scale-up process which forms part of NPD within the chemical process industries. Scale-up involves investigating the behaviour of a chemical process, and the nature of the engineering necessary to implement it, through a series of experiments at gradually increasing scale, starting in the laboratory and ending (if all proves satisfactory) with a working pilot plant. The scale-up process has several characteristics which together make it unsuitable for management by conventional workflow systems, and mandate an artificial intelligence approach to management:

- It is a highly interdisciplinary process, requiring the co-ordination of individuals from many different engineering and business specialities.
- Many ad-hoc processes occur, which nonetheless are long-time activities and require specific technical and business skills and resources to perform, therefore needing careful management.
- The structure of the process followed is highly flexible—varying from one project to the next, so that each scale-up process is unique.

- The process is information-intensive: a significant quantity of technical information of different types is generated and must be distributed to interested parties reliably and efficiently.

The approach adopted by the TBPM project project is based on work carried in the Enterprise project [9], and centres around an intelligent workflow engine which includes an interactive process planner. The planner uses artificial intelligence techniques based on the O-Plan architecture [3] to assist in the planning of tasks, while permitting the user to participate in planning decisions.

All system components operate on the basis of knowledge-rich models of the processes and of the context within which they occur (organisational structure, etc.). Jarvis et al [5] outline how such knowledge can be captured, structured, and represented in a workflow system.

An agent-based architecture supports the execution and co-ordination of the planned process among multiple participants distributed across a computer network.

The use of domain ontologies is a key principle that underpins the TBPM approach, and is the subject of the remainder of this paper.

3 Ontologies

An ontology is defined by Uschold & Gruninger [11] as a "... shared understanding of some domain of interest ...". Key features of an ontology include:

- An ontology of some domain of interest identifies and precisely describes the important concepts in the domain and the valid relationships between these concepts.
- The set of important terms and their definitions are agreed between all participants within the domain, and thus form a basis for communication about the domain.
- An ontology can be specified independently from the intended application for which it is developed. This enables its re-use for other purposes and applications touching the same domain. By separating the ontology (i.e. the language and concepts) of a domain from the uses to which it is put, different applications are enabled to use the same domain ontology, and thus to communicate in terms of this shared ontology.
- An ontology can be formalised and thus support communication between IT systems as well as between humans.

The main benefits accruing from the use of ontologies are:

- Ontologies support communication by providing a shared vocabulary with well-defined meaning, thus avoiding ambiguities and misunderstandings. They can support communication between any agents whether they are human agents or software agents. This is particularly useful in situations where experts from different fields need to work together, as is the case in NPD.
- In order to provide flexible support in a non-trivial business situation (such as NPD), models of different aspects of the domain have to be interrelated to make best use of them. However, it is difficult to capture different domain models in a way that takes their relationships into account. Using ontologies, it is possible to specify related models independently, thus reducing the difficulty of capturing domain models.

4 Ontologies in Scale-Up

4.1 Ontologies Required

Using the outline method for developing ontologies suggested by Uschold & Gruninger [11], the following ontologies have been identified as relevant in the context of intelligent workflow support for the scale-up process:

- **Artifacts.** The physical components and equipment which comprise chemical plant, and the chemical processes which take place within them. Example terms: distillation column, pipe, voltmeter, mix, filter, distill, react.
- **Information.** The types of information, its content, format, and physical manifestation, which are used, generated and transferred during the scale-up process. Example terms: design, cost estimate, sketch, engineering line diagram.
- **Tasks.** Describes in a generic manner tasks and processes which are commonly carried out as part of the scale-up process. Example terms: design, experiment, review, sanction.
- **Organisational Structure.** The organisational structure within which scale-up takes place, including the static organisation of the business as a whole and of project teams for specific scale-up projects. This includes the specification of roles which may be taken by individuals within the organisation. Example terms: organisational unit, manage, project manager, financial controller, engineer.
- **Capabilities.** Describes the domain-specific skills which may be possessed by participants in the process. Example terms: design, perform experiment, analyse.
- **Agents.** Describes the participants in the scale-up process. Allows the specification of both human agents and intelligent software agents. There is a strong link with the capabilities ontology—agents possess capabilities, which enable them to participate in the process. Example terms: engineer, software agent, research chemist.
- **Computer Support.** Covers the underlying infrastructure of computer hardware and software on which the information-centred parts of the process are conducted. Example terms: word processor file, edit, store, host, server.

In some of these areas there are valuable sources of information and existing ontologies which can be used or adapted to our purposes. The main sources of information are standards such as [8], [10] for representing tasks and processes, [6] for modelling the domain of chemical engineering, and the Enterprise Ontology [12], which provides a generally applicable ontology of business enterprises.

The ontologies described above are not independent. A step not included in the outline method in [11] but which was found to be necessary in order to integrate several ontologies into a functional system in a coherent manner is the identification of dependencies and relationships between the ontologies used. The relationships between the ontologies in the context of intelligent workflow support are shown in Figure 1. UML package diagram notation is used, with the addition of labels describing the nature of the relationships.

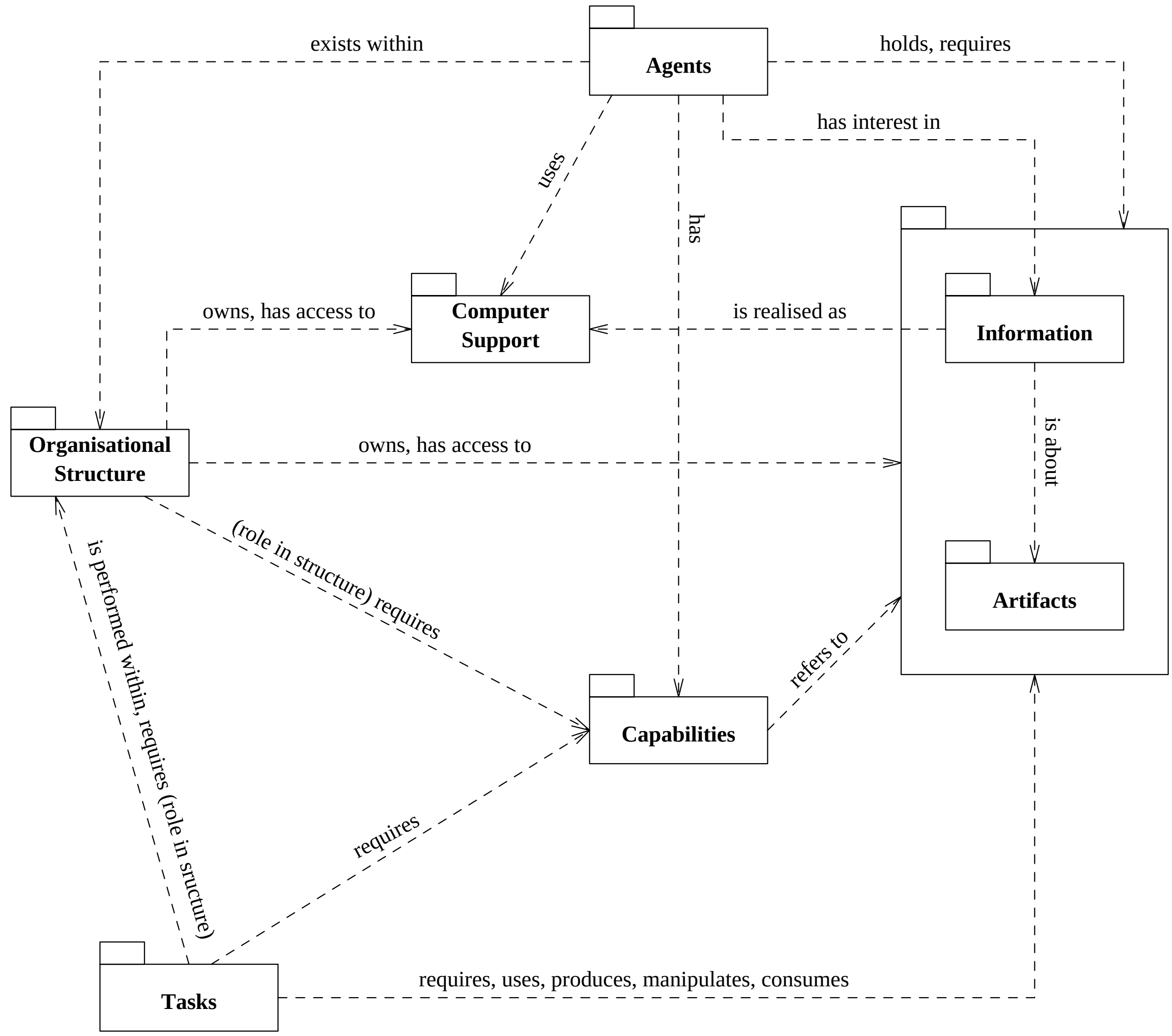

Figure 1. Relationships between Ontologies

4.2 Using the Ontologies

There are several ways in which ontologies are used in supporting the scale-up process at different phases. During the specification phase, in which domain models are captured in preparation for process support, the following benefits can be achieved with the help of the ontologies:

- During the specification phase independently specified models can be related by using intelligent matching techniques that take advantage of ontology terms and their relationships. For example, given an appropriate information ontology, a system can work out that an “equipment capital cost estimate” is of interest to somebody who has expressed an interest in “project financial information”.
- The agents ontology can help to infer an agent’s capabilities and interests by looking at the agent’s type. For example, a human agent who is a mechanical engineer can be assumed to be able to analyse technical information relevant to mechanical equipment.
- The capabilities, tasks, and information ontologies all support the process of turning software systems into agents by providing a well-defined, common interface for communication.

During active process support, the ontologies are used in the following ways:

- To determine which process models can be used to perform a given task, the system can use the tasks ontology to match user task requirements with available process fragments.
- To ensure that the most suitable agent is selected to perform a task, the system can use the capabilities and organisational structure ontologies to check that the agent has the capabilities and authority required to perform the task. The system uses the ontologies to match agent specifications with process specifications.
- To determine a suitable style of negotiation during delegations the system can use the organisational structure ontology to determine the relative status of the agents involved.
- To pass information along the process and between agents, the system can use the information ontology to match between a task's information requirements and information generated by other tasks in the process.
- To ensure information is passed to interested agents, the system can use the information ontology to match between agents' declared interests and information generated by the process. The roles defined within the organisational structure ontology can be used to infer some of the interest of agents.
- The system can use the computer support ontology to discover the format in which information is available in and, and determine whether and how agents can communicate using that format.
- During both process enactment and specification, human users can use all the ontologies to ensure that they understand the relevant concepts (i.e. processes, information, etc.)

5 Conclusion

New product development and chemical process scale-up are difficult processes to manage due to their complexity, interdisciplinary nature, need for flexibility, and conflicting requirements. However, they are key processes in many chemical engineering businesses, and therefore their correct and effective management is essential.

Current workflow systems do not provide the flexibility required for computer-supported management of dynamic processes such as these. Intelligent workflow has the potential to provide such support, but it needs to be underpinned by ontologies in order to provide it. Several distinct but related areas have been identified in which ontologies are necessary for support of the scale-up process. Ontologies thus form a vital adjunct to intelligent workflow techniques, particularly in the area of new product development. They can enable an intelligent workflow system to provide real support in day-to-day engineering situations.

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