Arbeitsbericht Nr. 14, Juli 1999

Workshop

„Intelligente Softwareagenten und betriebswirtschaftliche Anwendungsszenarien“

Prof. Dr. Stefan Kirn, Dipl.-Wirtsch.-Inf. Mathias Petsch (Hrsg.)

Technische Universität Ilmenau
Fakultät für Wirtschaftswissenschaften
Wirtschaftsinformatik 2

Ontology-based coordination of planning activities in networks of autonomous production facilities using multi-agent systems

Stephan Zelewski, Jukka Siedentopf
University of Essen, Department of Economics (FB 5),
Institute of Production and Industrial Information Management
Universitätsstraße 9, D – 45141 Essen
{stephan.zelewski/jukka.siedentopf}@pim.uni-essen.de,
http://www.pim.uni-essen.de

1 Outline

Subject of the proposed research project is the coordination of production networks based on multi-agent system technology (MAS technology). An *ontology-based communication* module permitting semantic representation of data, information, and knowledge structures as well as syntactical representations will be developed within a network oriented planning system. The project focuses on networks whose components ("units") are autonomous agents, but with a coordination of these agents' activities being considered as an essential requirement. Examples are the vertical cooperation along the supply chain or the horizontal coordination between dispersed, autonomous production facilities, especially of virtual enterprises. In this context, application of MAS technology is regarded as a fundamental requirement for developing and implementing adequate coordination systems rather than as an alternative to conventional, locally planning approaches.

Within the intended project, MAS technology performs two functions:

a) As a *modelling technique* it *describes* and *explains* the behaviour of a real-world networked system.

b) As a *development technique* it serves for the *implementation* of integrating – not necessarily integrated – software systems, with autonomous planning agents being subjects of integration.

Different autonomous planning units may use different *planning languages*. Therefore, merely syntactical representation of information or knowledge exchange processes is not adequate. Even if syntactical differences of internal data *structures* or *models* can be handled by using standardized interfaces, semantic differences of the *utilization* of these structures can-

not. Thus, an intelligent ontology-based communication module ensuring *terminological consistence and coherence within the languages* used by different planning agents (nodes) will play an essential role in the *coordination* of planning activities.

A minimum of coordination requirement can be derived from the assumption of a superordinated planning instance: Every agent-specific terminological element to be planned by such a superordinate instance has to be defined ontologically. Starting from this minimum requirement, extensions will be identified facilitating node-to-node communication. This is an indispensable prerequisite of a *cooperation-based planning*. In addition, different levels of autonomy will be distinguished regarding their effects upon interface modelling.

2 Objectives

2.1 Communicability

The intended project's first goal is to *improve the communicability of production-related expert knowledge* in the context of short-term adaptation of existing plans, especially due to unexpected disruptions (e.g. in the context of *re-scheduling*). In addition, prerequisites for the implementation of effective operational coordination tools will be formulated. Two subobjectives are derived:

Ontologies which can formally be proved as *common* and *re-usable* will be developed. The suitability of these ontologies will be tested for different reference scenarios – for different user groups (e.g. management of different production facilities) as well as for different production situations.

Ontology-based *reference models* will be supplied for the data, information, knowledge, and process structures facilitating a coordinated short-term adaptation of plans in networks of autonomous planning agents (production facilities, network nodes).

2.2 Integration and consolidation

Secondly, *integration and consolidation of ontologies* is sought. These purposes are derived from findings of two research areas: On the one hand, formally standardized languages for the implementation of and the communication between intelligent agents constitute a pillar of multi-agent system research, particularly in the context of speech-act theory. On the other hand, the conceptualization of domain-specific expert knowledge – especially the explicit semi-formal and formal specification of conceptualizations (*ontology design*) – is another

main research topic in the area of artificial intelligence, located in the area of knowledge engineering/knowledge management. Furthermore, the development of multi-agent systems requires the consolidation of *different* ontologies on object-level resulting in *shared ontologies*. This is of particular interest in case of heterogeneous distributed planning systems in an enterprise network sharing common (superior) objectives. From an outside perspective, such a *virtual enterprise* appears as an integrated system using one consistent and coherent ontology. The integration and consolidation of heterogeneous terminologies can be regarded as a very recent, not yet fully developed field of research within ontology design. Due to the importance for the success of the intended project, gaining new findings within this field of ontology design becomes a separate research objective.

2.3 Evaluation

The third goal is the *evaluation of ontologies using reference models*. A reference scenario of short-term plan-adaptation problems in a network of autonomously planning production facilities using different domain ontologies serves as common basis for the formulation of (domain-specific) process models, for domain-independent reference models, and for the a prototypical implementation of an internet-based multi-agent system. The empirical evaluation process applies to those parts of the ontologies involved (domain-specific or domain-independent), which are crucial for the communication between the production facilities. The layout of the evaluation process itself depends on the architecture of the ontology consolidation system (see below).

2.4 Standardization

The fourth goal addresses *standardization* aspects: Competitive standard tools for the development of ontologies will be analyzed and evaluated. The use of standardized instruments is considered as a prerequisite for the consolidation or integration of different ontologies, and thus for the development of shared ontologies.

3 Working areas

The proposed project focuses on the support of *information logistics* in networks of autonomous production facilities. Within this framework, three topics will be investigated (Figure 1):

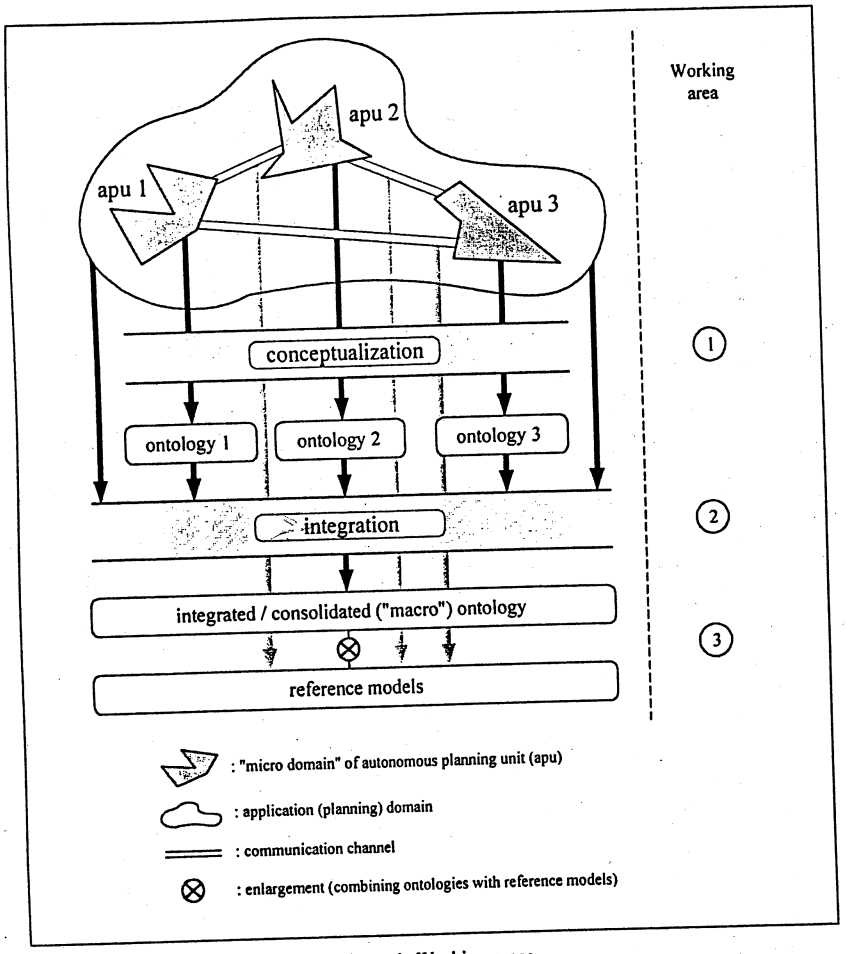

Figure 1: Working areas

3.1 Conceptualization

Conceptualization means to isolate and structure the knowledge about short-term adapting plans of different nodes in a production network. This step results in ontologies as *explicit* semi-formal or formal *specifications* of conceptualizations. Each conceptualization of (isolated) node-specific knowledge items reflects the initial conditions of the proposed research and development effort: Isolated planning activities in a network of autonomous production facilities. Such conditions are typical e.g. for independent enterprises comprising supplier- and/or engineering-networks which are discussed especially in the context of sourcing policies, and can be found as well in the context of manufacturing networks, e.g. in networks of autonomously acting subsidiaries of a world-wide production network. This facet is discussed especially in the context of global manufacturing. Due to planning autonomy it must be assumed that the network nodes – the planning agents – do not use the same terminology and semantics to communicate their individual declarative, algorithmic, and processual planning knowledge. Rather, there are several – at least partly – incompatible terminological and semantic islands.

3.2 Integration

The second step covers the integration and consolidation of the ontologies previously formulated for the individual autonomous agents. The result should be a framework which can serve as an *integrated ontology* for the network of autonomously planning agents. For that purpose, in addition to the knowledge used to adapt plans separately, the *procedural* and *structural knowledge* used to take coordination decisions within the network is specified in a formal way. Thus, the aim is to find a conceptualization and specification of the node-spreading procedural and structural *"network-knowledge"*.

It should be pointed out that the subject of integration is not to develop a closed singular ontology. Rather, those parts of agent-specific ontologies which are crucial for the communication within the network will be identified. These are especially those parts which are characterized by inconsistent descriptions of communication-relevant knowledge components in different agent-specific ontologies, e.g. *"speech barriers"* due to homonymously used terms. The process of achieving and maintaining (knowledge-) consistency will affect these partial ontologies exclusively. Within the intended project two competitive integration strategies will be examined: First, consistency can be achieved by eliminating crucial inconsistencies in the agent-specific ontologies (*forced internal consolidation*). Second, *communication interfaces* (serving as translation units) will be embodied in the *network-ontology* (*external consolidation*).

3.3 Reference models for coordination issues

The third main topic is to *enlarge* the network-ontology by *reference models* for those information and process structures, which are necessary for the coordination of agent-specific short-term plan-adaptations.

4 Methodology

Predominantly, *empirical methods* will be used in the intended project[1]. The conceptualization of expert knowledge about plan adaptation will be exemplarily carried out within selected cooperating enterprises. A major task is the *identification of terminologies* used as well as the semantic *explication of the terminological entities*. Concerning empirical data collection, personal interrogation – structured and non-structured interviews – is of particular importance. However, pre-structured written collection techniques, e.g. questionnaires, are not suitable to discover the meaning of special "termini technici", which are associated with enterprise-specific terms and/or even context-specific individual (non-standard) semantics which the involved employees are not conscious about. Nevertheless, even "paper-based" (written) and electronic collection techniques will be considered as supporting tools, e.g. for the analysis of existing data models, which are (at the very best) available in decision support systems, in particular in production planning and control systems.

The identification and (re-)construction of the communication-crucial partial ontologies are based on *linguistically founded methods of analysis*, which tap the semantic, but also the pragmatic dimensions of technical terminology. Among these methods are, for instance, analytical techniques of speech-act theory, which have occasionally been used in the context of the multi-agent systems research. Additionally, analysis methods for structuring complex knowledge bases on the knowledge level (known from AI research) supply to the methods toolbox.

Both the ontology design and the implementation of a multi-agent system prototype will be accomplished by using available "standard methods". On the one hand, the selection of a specific method will be based on an analysis of its relevant characteristics. For this purpose it is suitable to rely on scientific publications, even product descriptions, and in particular on experience exchange. On the other hand, suitability of specific methods regarding project-specific prerequisites will be evaluated *experimentally*. The project-specific prerequisites will be obtained by a *deductive analysis* of design and implementation problems.

1) Of course, software engineering methods – even non-empirical ones – are essential, too. Nevertheless, they are not pointed out here.

5 Excluded Research Topics

Linguistic research topics: Naturally, the development of an ontology has a linguistic dimension. However, due to the orientation of the proposed project – and the scientific background of the involved researchers – linguistic aspects will not be treated in more detail than roughly described above. Linguistic research topics are of minor importance, because only the *semantics of singular terms*, but not the *structures of the languages* used for planning purposes are to be analyzed.

Professional software/system development and implementation: The implementation of an internet-based multi-agent system prototype merely serves as a feasibility study, pointing out the fundamental feasibility of distributed plan adaptation in a network of autonomously planning production facilities. However, the implementation of an *operational software system* is outside of the project team's core competence.

6 Concluding Remarks

The intended project aims at the development of effective and efficient *planning tools for enterprise networks*. It is based upon findings of recent, not yet completely developed research areas located in business administration as well as in computer science. In particular, there is a lack of reliable rules for the selection of methods and standards to be applied. Thus, access to the knowledge of proven experts seems indispensable. The project differs fundamentally from other projects applying either proven computer science technologies to new economical problem definitions or new findings of computer science to problem definitions from the field of business administration.

The technologies to be applied within the intended project originally stem from distinct interdisciplinary research areas. This applies to both the multi-agent system research, which is settled mainly in the area of *distributed artificial intelligence*, and other disciplines dealing with decision and coordination processes in complex and heterogeneous systems (e.g. *coordination science*). Because of this *interdisciplinary context*, any analysis of available research work remains inevitably incomplete without *involving experts from several disciplines*, not only from business administration and computer science but especially from the domain(s) concerned. In addition, a network of cooperating enterprises and researchers can serve as a suitable platform for the implementation of a close-to-reality prototype of a distributed, internet-based multi-agent system.

Related literature:

[1] Bird, S.D.: Conceptualizing a shared language subsystem for distributed decision support systems, *Decision Support Systems* 19 (1997), pp. 227-235.

[2] Ceroni, J.A., Matsui, M., Nof, S.Y.: Communication-based coordination modeling in distributed manufacturing systems, *International Journal of Production Economics* 60-61 (1999), pp. 281-287.

[3] Fensel, D., Decker, S., Erdmann, M., Studer, R.: Ontobroker: The Very High Idea, Proceedings of the 11th International Flairs Conference (FLAIRS'98), Sanibal Island 1998, pp. 131-135.

[4] Fox, M.S., Grüninger, M.: Ontologies for Enterprise Modelling, in: Kosanke, K., Nell, J.G.: Enterprise Engineering and Integration: Building International Consensus, Proceedings of the ICEIMT '97, Berlin, Heidelberg, New York et al. 1997, pp. 190-200.

[5] Guarino, N.: Understanding, Building, And Using Ontologies, *International Journal of Human-Computer Studies*, 46 (1997) 2/3, pp. 293-310.

[6] Gruber, T.R.: Towards Principles for the Design of Ontologies Used for Knowledge Sharing, Technical Report KSL 93-04, Knowledge Systems Laboratory, Stanford University, Stanford 1993.

[7] Hadjiconstantiou, E. (ed.): Quick Response in the Supply Chain, Berlin, Heidelberg, New York et al. 1998.

[8] Jennings, N.R.: Controlling cooperative problem solving in industrial multi-agent systems using joint intentions, *Artificial Intelligence* 75 (1995), pp. 195-240.

[9] Kraus, S.: Negotiation and cooperation in multi-agent environments, *Artificial Intelligence* 94 (1997), pp. 79-97.

[10] Le Ber, F., Chouvet, M.-P.: An agent-based model for domain knowledge representation, *Data&Knowledge Engineering* 29 (1999), pp. 147-161.

[11] Lemaitre, C., Excelente, C.B.: Multi-agent network for cooperative work, *Expert Systems with Applications* 14 (1998), pp. 117-127.

[12] Satapathy, G., Kumara, S.R.T., Moore, L.M.: Distributed intelligent architecture for logistics (DIAL), in: *Expert Systems with Applications* 14 (1998), pp. 409-424.

[13] Uschold, M., Gruninger, M.: Ontologies: principles, methods and applications, *The Knowledge Engineering Review*, 11 (1996) 2, pp. 93-136.