
Support for virtual organisation creation – partners' profiles and competency management

Jiří Hodík* and Jiří Vokřínek

Gerstner Laboratory
Department of Cybernetics
Czech Technical University in Prague
Technická 2, 166 27 Prague, Czech Republic
E-mail: hodik@labe.felk.cvut.cz
E-mail: vokrinek@labe.felk.cvut.cz
*Corresponding author

Petr Bečvář

CertiCon, Software Development
Vaclavska 12/316, 120 00 Prague, Czech Republic
E-mail: becvar@certicon.cz

Abstract: The only possibility for Small and Medium Enterprises (SMEs) to succeed in marketing competition with big corporations is cooperation and sharing of knowledge and resources. A promising way to cooperate and keep their independence is the formation of semipermanent collaborative networks, which facilitate Virtual Organisation (VO) creation and management. This work concentrates on the maintenance and facilitation of partners' profiles and competency management in such networks. The aim of our effort is to support potential partner identification during the VO creation and adaptation processes, as well as the facilitation of advertisement of oneself to be identified as a potential partner. The contributions of the work are the definition of competency and profile-related terms, the description of competency structures and an architecture of a competency and profiles management system, as well as a prototype verifying the presented theoretical work in a real business environment.

Keywords: virtual organisation; competency management; network; prototype; software agent; electronic business; e-business; applications.

Reference to this paper should be made as follows: Hodík, J., Vokřínek, J. and Bečvář, P. (2009) 'Support for virtual organisation creation – partners' profiles and competency management', *Int. J. Agent-Oriented Software Engineering*, Vol. 3, Nos. 2/3, pp.230–251.

Biographical notes: Jiří Hodík works as a Research Fellow at the Agent Technology Center of the Gerstner Laboratory, Czech Technical University in Prague. He graduated with a degree in Technical Cybernetics in 2001. His research interests include artificial intelligence, multi-agent systems, auctions, multicriteria decision-making, virtual markets, trust and reputation building and management and virtual organisations. During his visiting scholarship at the State University of New York at Binghamton, he worked on immune system methods for information security.

Jiří Vokřínek is working as a Researcher at the Agent Technology Center of the Gerstner Laboratory, Czech Technical University in Prague. He has a university degree in Replanning in Multi-Agent Systems. His research interests are artificial intelligence, multi-agent systems, planning and replanning in manufacturing, virtual organisations, supply chain management and logistics. He participates on several research projects focused on agent-based planning and simulation.

Petr Bečvář received his PhD in Technical Cybernetics from the Department of Cybernetics, the University of West Bohemia in Pilsen, Czech Republic. From 2000 until 2003, he worked as a Researcher at the Center of Applied Cybernetics. He now works as a Researcher at the Department of Cybernetics, the University of West Bohemia in Pilsen and as a Software Analyst at CertiCon. His research interests include multi-agent systems, process classification, expert systems, technical diagnostics and intelligent human-computer interfaces.

1 Introduction

In business-to-business e-commerce, collaborating partners may act as a single company and, thus, create a more competitive whole (Browne and Zhang, 1999; Preece *et al.*, 1999). Such networking and integration of Small and Medium Enterprises (SMEs) is a natural evolution that reflects the acceleration and increasing complexity of business opportunities (Říha *et al.*, 2002). On the other hand, a large company may split its organisation structure into a network of small units to improve concentration on various markets segments (Konsynski, 1993). Most of the forms of virtual integration created to improve cooperation among independent entities (Hagel and Armstrong, 1997) are covered by network organisations (production networks, supply chains, Virtual Organisations or VOs, *etc.*). To work effectively, information technologies are crucial for networked organisations (Konsynski, 1993).

Referring to previous works on networked organisations, Lemaignan *et al.* (2006) defined the manufacturing domain to be a sum of *resource*, *process* and *product* concepts and manufacturing consisting of controlling them and their linkages. The latter are handled by information systems, rules and a common dictionary. In a decentralised environment, web-based cooperative teamwork support has a significant impact and it is more effective than management tools based on manual work (Yang, 2000).

This work concentrates on the methodology for profiles and competencies management for networks of SMEs. The targets of this work are the simplification and integration of cooperation between the partners facilitated by means of sharing information about their competencies. It is crucial for effective collaboration (not only) in networks forming VOs because information is their blood (Adesta, 2005). The goals of this work are:

- *The general management of profiles and competencies*

As the common terminology is not unified, it is necessary to define the appropriate terms relating to the competency and profile management domain. This definition should contain correct definitions of the relations between the defined terms. To

support the establishment of structures for the maintenance of competency, defining the relation types between competencies is needed. This task also contains definitions of the metrics for measuring the similarity of two competencies.

- *The search for competent partners for collaborative business*

Within this task, a concept of tools for competency search as well as announcement (to allow anybody to be found as a potential partner) should be defined. As this work deals with VOs formed from mutually independent partners organised within some kind of network, the natural characteristics of such a network should be reflected.

The results presented in this work are beneficial mainly during the creation and evolution phases of the VOs life cycle.

2 Related work

As networked organisations are distributed, fully centralised solutions are often not suitable for them. It is because of the distributed manner and autonomy of subjects of which such organisations consist (Preece *et al.*, 1999). This section introduces the related work in relevant domains.

2.1 Multi-agent systems

The multi-agent technology is able to provide an effective platform that naturally supports the key feature of networked organisations – distributed resources' allocation and maintenance (*e.g.*, in VOs) is one of the basic problems studied in multi-agent systems (Voos, 2006). A multi-agent system is a technology of distributed artificial intelligence. It is based on agents which are (by a widely accepted definition) independent autonomous software or hardware units which may operate in a cooperative as well as competitive environment. This technology is used to link logically or geographically distributed systems together or model the negotiation and coexistence of such systems and their components. The domains for agent (the multi-agent) technology application in collaborative networks are *network design, the operation of a network and the modelling of a network* (Wiendahl and Lutz, 2002). In a workflow management of networked (virtual) organisations, the agents are utilised to *advertise their capabilities, exchange rich information and synchronise workflows at a high level of abstraction* (Preece *et al.*, 1999).

Different requirements may lead to different agent types. For us, the agent is *an agent of someone* and plays any of the following roles:

- *Model* – for a defined domain, the agent is a model (a model is anything that has required attributes that are sufficiently similar to the attributes of the original) of the partner to emulate the partner's behaviour.
- *Representative* – it is a tool used for cooperation/collaboration with others. Negotiation with an agent within the scope of its capability is equivalent to negotiation with the partner that is represented by the agent.
- *Assistant* – an agent's task is to acquire and analyse information in order to support the decision making of the assisting agent's owner.

2.2 Concept of a virtual organisation

A VO is understood (e.g., Faisst, 1997; Van Wijk *et al.*, 1998; Gruber and Nöster, 2005) to be "... a specific form of network organizations". Gruber and Nöster (2005), as well as Van Wijk *et al.*, 1998) specified their key features (also defined by most of the other definitions) as *the extensive use of information technology to coordinate the partners, sharing risk and knowledge with partners* and *focus on core competencies* (Gruber and Nöster, 2005). The other commonly mentioned features are (e.g., Faisst, 1997; Capó *et al.*, 2004): *the autonomy and independence of members, operating towards the customer as a single company* and *temporality of an existence which is mission-oriented*. The most often mentioned features are distribution of members and *slight bureaucratic overhead* and presenting *one face to the customer* (Faisst, 1997).

The VO members are *autonomous* (each entity is an independent company (or freelancer) with its own interests, commitments and goals), *distributed* (entities are naturally distributed in the real world) and *heterogeneous* (each entity may use different technologies and procedures) (Camarinha-Matos and Afsarmanesh, 2004). All these aspects are directly addressed by distributed artificial intelligence and its component of multi-agent technologies (Molina *et al.*, 1998) that have already been utilised in the domain of VO: e.g., Fischer *et al.* (1996) defined VO and the employing agents in it and Petersen *et al.* (2001) described the use of agents for modelling a virtual enterprise (subset of VO).

Most of the VO definitions are mutually consistent; the only conflicting feature which is adopted by some definitions and not required by other ones is *sharing risk with partners*. An adoption or not of this feature is not crucial for this paper.

2.2.1 Virtual organisation life cycle

Many definitions of the VO life cycle exist in the literature. We have adopted a basic one, which is probably the most common. It consists of three phases:

- 1 collaboration preparation phase (*i.e.*, VO formation)
- 2 value adding phase (*i.e.*, VO operation)
- 3 collaboration dissolution phase (*i.e.*, VO dissolution).

Potential VO adaptation is usually covered by Phase 2 (VO operation) or in an additional evolution (or perturbation) phase. Such a model is presented, e.g., by Camarinha-Matos and Afsarmanesh (2004) or Shao *et al.* (2004).

This work concentrates on the processes of collaboration preparation and adaptation.

2.2.2 Network behind a virtual organisation

Behind a VO, there could be a stable network or pool of entities that intend to cooperate repeatedly (Faisst, 1997). Such a network is created to support the business of SMEs, e.g., in case traditional markets are lost due to globalisation (Camarinha-Matos and Afsarmanesh, 2004). According to Faisst, the background network may be formed by big enterprises to clarify their organisational structure or create a network of suppliers. On the other hand, the network may be formed by SMEs to cover all the business aspects and opportunities that they cannot satisfy on their own (Faisst, 1997).

The network may be also created and supported by subjects like government agencies that participate in the network only indirectly. The idea of a background network was improved by Camarinha-Matos and Afsarmanesh (2004), who introduced the Virtual Organisation Breeding Environment (VBE), defined as:

“... an association or pool of organizations and their related supporting institutions that have both the potential and the will to cooperate with each other through the establishment of a ‘base’ long-term cooperation agreement. ... Industry clusters or industry districts are examples of such breeding environments.”

Supporting institutions help the network’s members with communication, knowledge sharing and the whole life cycle of VOs.

An electronic institution framework for VO life cycle support has been introduced by Rocha and Oliveira (2001). The electronic institution is defined as both the tools and services to support the:

- identification of the needs (description of product or service to be delivered by VO)
- partner selection (automated selection of individual organisations based on knowledge, skills, resources, *etc.*)
- operation (control and monitoring of VO, VO reconfiguration)
- dissolution (distribution of profits, information storage for future use).

2.3 Information sharing

In order to find the best possible partners to establish a new VO, the enterprise can: (i) publish information about itself or (ii) search for information published by others to find the appropriate partners. An ‘e-catalogue’ of partners’ profiles and competencies is an information maintenance system that the network members contact in order to publish information about their offers and requirements, as well as for searching the offers and requirements of others. Depending on a particular network, the e-catalogue generally has different features.

The data management model differentiates catalogues as centralised, decentralised and hybrid:

- *Centralised catalogue* is a system under the control of one subject, which may be responsible for the validity and completeness of provided information. One example of such a system, which is not dedicated to a specific network, are the chambers of commerce.
- *Decentralised catalogue* is a system of the knowledge bases of individual network members. It is mostly open, as it misses a centralised element that could be supervised or administrated. Examples of decentralised information sharing is, *e.g.*, the Peer-to-Peer (P2P) network or a set of websites of all network members.
- *Hybrid catalogue* is a system which contains both centralised and decentralised elements which are combined to exploit the features of both the previous models together with minimising the impact of their disadvantages. An example of a hybrid catalogue is the e-Cat presented in this paper (see Section 4).

Each of the defined catalogue types offers some positive and negative features. There are several criteria to decide which information should be better kept centrally and which should be distributed. The motivations for central information storing are, *e.g.*, keeping information consistent among all partners or a requirement for certified information revision publishing. On the other hand, if information is changing dynamically or its provider requires controlling access to the information, it should remain distributed on the sides of the providers. If the information is necessary for a time-critical decision, it should be maintained in a local copy of each consumer independently of whether the original information source is centralised or distributed.

A common solution used for document management in networked organisations consists of a central point maintaining the shared documents and enabling access for all team members (Linn, 1999) (*e.g.*, central point-based version control systems Concurrent Versions System (CVS)¹ and Subversion (SVN)² used in software development). The problem of information sharing in distributed systems is also addressed in the research of distributed databases (Sheth and Larson, 1990) (or, *e.g.*, by Git,³ a version control system without centralised server). Partially centralised approaches use specialised agents (Masaud-Wahaishi *et al.*, 2003; Mařík and Pěchouček, 2004) like mediators, brokers, matchmakers or facilitators.

Friese *et al.* (2003) compared the features of centralised (client-server architecture) and distributed technologies for information management. Without a central server, bottlenecks and single points of failure are avoided and individual peers keep their independence. On the other hand, network administration lacks any central control, which is required in some domains to ensure the consistency and verity of data within the network. Yan *et al.* (2006) also discussed the weaknesses (mainly architectural limitations) of conventional workflow management systems: poor performance, lack of reliability, limited scalability, user restriction and unsatisfactory system openness.

2.4 Concepts of distributed information sharing

Examples of distributed architectures for information sharing during the VO creation process and further workflow management tasks are: P2P networks, grids and multi-agent systems.

The P2P network is a distributed technology consisting of mutually independent entities (peers) having physical and logical resources respective (Friese *et al.*, 2003). The only effort required for a peer to connect to a P2P network is to implement the corresponding network protocol (Schmees, 2003). In order to distinguish between different kinds of networks, Friese *et al.* (2003) defined (beside the centralised architecture) a pure P2P network as consisting of 'equal' peers and a hybrid P2P network as containing specialised nodes for certain functions. Friese *et al.* (2005) presented a resource management framework used in a P2P business resource management framework for managing resources such as web services and business process execution engines. The P2P architecture may be also utilised for decentralised the workflow management system of VO (*e.g.*, SwinDeW by Yan *et al.*, 2006).

The maintenance of distributed and heterogeneous knowledge bases is also studied in works oriented to grid technology. Examples of such works, which are oriented to the VO domain, are the Constraint-Oriented Negotiation in an Open Information Services Environment (CONOISE) and Constraint-Oriented Negotiation in an Open Information

Services Environment – Grid (CONOISE-G) projects (Norman *et al.*, 2004; Oren *et al.*, 2005; Patel *et al.*, 2006). The CONOISE system architecture can be denoted as a hybrid because it consists of several supporting agents (active meta-agents) and agents representing the ordinary members of the network. The ordinary member is denoted as a service provider, but it is allowed to provide no service as well. In the CONOISE system, to be found as a service provider, the agent must advertise the service to the specialised agent (Yellow Pages agent) that is part of the pool of the CONOISE tool-supported collaborative network. If somebody requests to form a VO, a specialised agent (Requester Agent) discovers the potential providers of requested services using the Yellow Pages agent. Supporting information about the reputation of the providers and their services is provided by the Quality Agent. If the Yellow Pages agent is not reachable, the VO formation is not possible. Another limitation is in the limited control of a network agent over the VO formation process.

Another example of a distributed architecture is the multi-agent technology. The (Knowledge Reuse and Fusion/Transformation (KRAFT) architecture presented by Preece *et al.* (1999) supports VO by ‘knowledge fusion’. Referring to earlier works, Preece specified two essential common mechanisms of successful integration to a VO: an *exchange of electronic documents* and a *synchronisation of workflows*. KRAFT employs the multi-agent technology to integrate all local data sources and other knowledge-processing components. The limitation of KRAFT is its orientation only to pure cooperative environments.

Multi-Agent Indexing and Query System (MAIQS) by Linn (1999) is an agent-based system which concentrates on cooperative document indexing and querying in geographically distributed networked environments of 5–20 workers collaborating in a P2P manner. Agents support their users by searching for and indexing workgroup data and documents. In MAIQS, there is no centralised data storage, register or broker; all information is stored on the workstations of the team members and its exchange is queried directly by the agents. The limitation of MAIQS is a need of an authority responsible for the maintenance of shared knowledge.

The systems presented provide interesting features, but also limitations. To build a fully operating system in today’s e-business, we have to focus on maximal possible decentralisation (minimising the risk of single points of failure and preserving autonomy and privacy) and the definition of common understandable concepts of advertised services. We present the concept of profiles and competencies management and the software tool supporting VO creation with two real case pilot implementations that are able to operate in modern dynamic e-business environments.

3 Concept of competency and related structures

Although the terms ‘competency’ and ‘competence’ could have slightly different meanings, both of them are used to describe the ability and capability of a subject that presents them as its competitive advantage. Defining competence, Neubert *et al.* (2001) referred to “the cognitive, conative and expressive abilities of humans to organise their activities in order to produce certain results”. Neubert *et al.* (2001) assumed competence to be a necessary prerequisite “realizing a business process to create valuable results” for each VO member. VO creation is the process of finding partners that are able to provide their competencies to cover an introduced business opportunity.

Core competency, as widely referenced, was introduced by Hamel and Prahalad (1990), who defined it as a competency that a company concentrates on (should concentrate) in its value-adding process as its competitive advantage. They also defined the rules for identifying which competencies are the company's core competencies. A core competency must be:

- significant in the value-adding process
- somehow unique if compared with the core competencies of competitors
- applicable to a wide variety of markets.

The processes that are not based on the company's core competencies could be outsourced to subjects concentrating on them as their core competencies. In such a case, outsourcing may be more effective (in costs and blocked resources) than operating such processes on their own. Fischer described a *core competence* of an enterprise as a set of skills, technologies and know-how crucial for the added value provided by the enterprise (Fischer *et al.*, 1996).

3.1 Competency

In the domain of distributed systems, there is no common terminology of competency management; the terms 'competency', 'competency class', 'competency instance' and 'profile' are used in several slightly different meanings. In the following text we try to unify the meanings of these terms. In some cases, the term 'competency' is used only for a competency class (*e.g.*, Biesalski, 2003; NASApeople⁴). On the other hand, *e.g.*, HR-XML,⁵ which is primarily focused on human resources management (but it is also easily applicable to another CNO domains), uses the term 'competency' both for the competency class and the competency instance as they are defined in this text.

Here, definitions of competency-related terms are suggested. The definitions extend our previous work in this domain (Hodík *et al.*, 2008). As the first step, competency and profile are defined:

- *Competency* is an ability to perform business processes which are supported by the necessary available resources, practices and activities, allowing the organisation to offer products/services.

For larger sets of competencies, taxonomy structures are used to organise them and describe the relations among them. Different sets of competency classes can use different description systems for the same competency. Thus, in different sets, the same competency can be described with a different amount of detail and different relations to other competencies.

- *The profile (of a subject)* contains two main elements: (i) general information about the partner and (ii) a set of competencies offered by the partner as their core competencies.

Within one network, one subject uses one profile which presents the subject's details to partners. In the case of membership in more networks, more profiles (one per group) are utilised by each subject according to each group's rules.

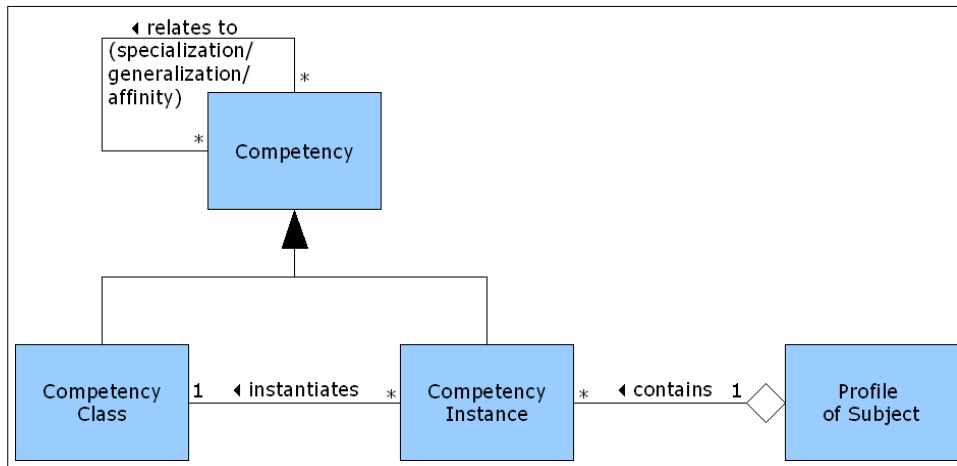
The competencies presented in the profiles are derived from commonly understood and accepted definitions in order to ensure consistency and avoid the misinterpretation of the presented competencies. To distinguish between the shared definition of competency and

the competency specific for the partner, the competency class and competency instance are defined. Figure 1 presents the relation between competency, its classes and instances and the profile of the subject.

- Competency class* defines the existence of a competency in the world; it distinguishes itself from the other existing competencies and defines relations to them. The competency class may be extended by defining the means used for measuring the level and robustness of the competency.

Every competency may have its specifying attributes (called Competency Evidence, according to HR-XML), which are defined in the competency class. Since the competency class is never connected to a particular subject (person or company), the specifying attributes do not contain any particular value. If a class is not specific enough, specialising classes may exist. Thus, every competency class can have its generalising and specialising class(es).
- Competency instance* refers exactly to one competency class related to one subject. If the competency class defines the means for measuring the level and robustness of the competency, the competency instance can optionally assign values to them. One competency class can be instantiated multiple times by various subjects. Each subject instantiates as many competency classes (each of them only once) as the competencies they offer.

Figure 1 The relation between competency, its classes and instances and the profile of the subject (see online version for colours)



3.2 Relations between competencies

As the competencies in the real world are more or less related, competency classes also provide for the descriptions of such relations. The possible relations of one competency to others are (see Figure 1):

- Specialisation* – a specialising competency may exist to extend the features of the original one that are not specific enough in some cases. This relation is directed.

- *Generalisation* – generalisation introduces an opposite to specialisation. A competency specialised by one or more competencies introduces a generalisation of all those competencies. This relation is directed.
- *Affinity* (also *relation to*) – a competency may be somehow related to another one, but the relation is neither generalisation nor specialisation; the relation may be unspecified – either due to its complexity or its intuitiveness. This relation is independent of the previous two relations and it is undirected.

The level of relation between the competencies connected by the relational links is measured by the *closeness*. It describes the similarity, relation or coherency between two competencies. It enables searching for an alternative competency if the desired one is not available (not instantiated by anyone or the competency owner is not available for whatever reason). It can be defined explicitly between every two competencies or defined as a metric using specialisation, generalisation and affinity relations.

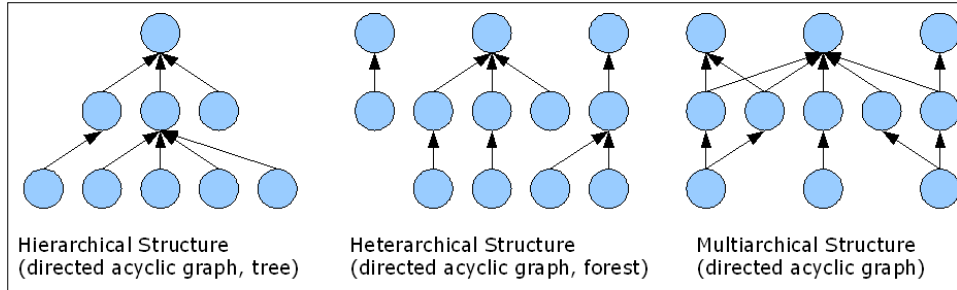
3.3 Competency structures

The allowed relations and their cardinalities are determined by rules that are defined by the structure of competencies. The structures are described by graphs, where the competencies are defined as nodes and their relations as edges. Although the common structure is the hierarchical one without affinity relations, more complex structures exist.

The relation of generalisation/specialisation correspond to directed edges and the relation of affinity (if present), to nondirected edges. None of the competency structures allows a cycle of directed edges. Therefore, no competency may be its own direct or indirect generalisation/specification. The common structures according to the ordering of the directed edges are (see also Figure 2):

- *Hierarchical structure* (directed acyclic graph, tree) – in this case, there is one general competency on the top of the structure. It introduces the root of the competencies. Each competency (except the top one) has defined exactly one generalising competency, while it may have defined several or no specialising ones.
- *Heterarchical structure* (directed acyclic graph, forest) – it is similar to the hierarchical structure, but several roots may exist.
- *Multiarchical structure* (directed acyclic graph) – there is no limitation for the number of any relation type for any competency if the acyclicity is kept. Each competency may have an unlimited number of generalising and specialising relations to other competencies. This structure is suitable when some competency belongs to various mutually independent groups of competencies.

The type of structure in which the competencies are organised has a strong impact on the competency search mechanism. For hierarchical structures, there is a relatively simple and explicit way of defining the closeness of the competencies (*e.g.*, number of edges between two competencies). For heterarchical structures, there may be defined an explicit nonparametric evaluation of closeness for competencies belonging to two disjoint trees while for multiarchical structures, even more complex metrics of closeness may be defined.

Figure 2 The graphs representing the structures of competencies (see online version for colours)

3.4 Searches for competency

The reason for the existence of information management tools is the search. In case information is included in the system, the appropriate class has to be chosen for instantiation and in case of a search for a competence advertiser, the competency instances are in the scope. There are various strategies for searching for the competency instance (as well as class):

- *Full text* – this is the simplest strategy, where all records (competency names) are matched against the mask to find the ones that contain the searched text string. Using this strategy helps in cases where the human user remembers a substring of the competency names and is able to find the correct one in the list provided by the search mechanism. The drawback of this strategy lies in the huge list of found records if the searched string is too general and no correct results if the searched string matches the synonym of the existing competencies' names.
- *Closest generalising competency* – this strategy is mainly for searching competency instances in a tree- like or multiarchical structure even if there is no instance of the searched competency. If the searched competency is known, this search returns an instance of the closest generalising competency.
- *List of specialising competencies* – this strategy is similar to the closest generalising competency search. If there is no direct instance of the searched competency, the list of all closest/all specialising competency instances is returned.
- *Closest neighbourhood* – this strategy provides similar results like the combination of the two previous strategies. Here, the closeness is assumed during the search and all competencies (instances as well as classes) within the defined neighbourhood are considered to be included into the result.

4 Concept of profiles and competency management – e-Cat

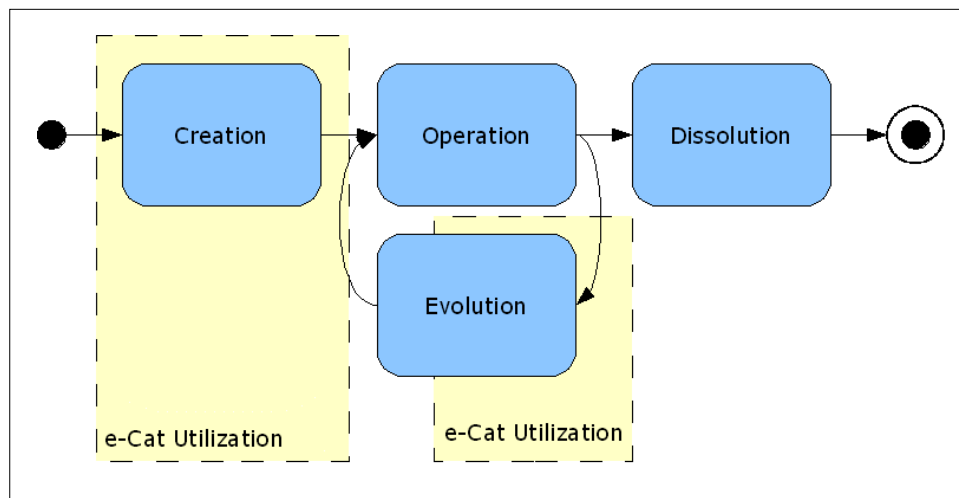
A collaborative network of independent SMEs is naturally distributed. Each of the involved subjects has its own business goals and private knowledge that are not intended to be shared. The presented technology takes this constraint into account and so it is based on distributed elements organised in a P2P network. On the other hand, the network's added value is a support of VO management processes by various centralised

components provided by the network's supporting institutions. Such institutions are defined, *e.g.*, by Rocha and Oliveira (2001) as electronic institutions. The networks may also support their members by means of tools for effective partner search, social knowledge management, negotiation support and others. The presented network members' profiling and competency management tool should provide in general three main services:

- 1 *Management of competency classes* – the commonly agreed ontology for describing partners' capabilities and definition of needs
- 2 *Management of network members' profiles* – based on competency classes instantiation and used for potential partners' selection
- 3 *Management of access rights* – to the information provided within the network.

The e-Cat is a concept of a tool for the facilitation (keeping, managing, distributing and searching) of members' profiles and competencies in collaborative networks of SMEs. The e-Cat supports the VO manager mainly during the creation phase and, if necessary, during the evolution phase of the VO life cycle (see Figure 3). During the creation phase, the VO team is being formed and the e-Cat is used to identify the potential partners. During the evolution phase, the new partner is included into the running VO. If there is a need or intention to search for partners during other VO phases or without forming any concrete VO, the e-Cat may be used as well.

Figure 3 The scope of the e-Cat in the VO life cycle (see online version for colours)



4.1 Architecture

The e-Cat is designed as a *hybrid catalogue* and utilises the multi-agent concept. It consists of centralised components and multiple agents representing individual network members. Such a hybrid P2P network architecture (Friese *et al.*, 2003) enables effective cooperation in a distributed environment where distribution ensures maximal independence among the network members and private knowledge preservation.

The identification and contact information of network members as well as the definitions of competency classes are maintained by network electronic institutions. Centralised network services support members by:

- ensuring the common understanding of competencies and understanding member's profiles within the whole network
- maintaining the identification information of members (centralised part of member's profile) to limit the access to the community only to the authorised members and prevent members from acting as another company.

Members' agents download information from central elements when needed and they may store a local copy of the centrally maintained information. The copy of frequently accessed information allows each member to use the tool, even if it is totally disconnected from the rest of the world. The centralised elements ensure a common understanding of competencies and profiles consistency. The hybrid nature of the catalogues enables full operation (because of local information copies), even in case of the temporary unaccessibility of centralised services.

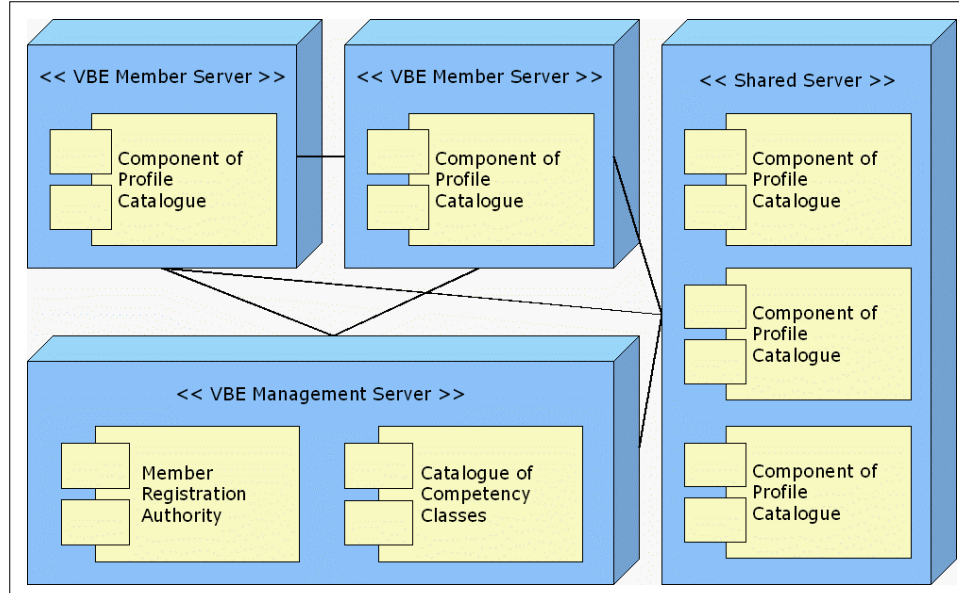
The distributed part of the e-Cat is based on agents representing and assisting individual network members. The profile of the company is considered public within the network. Any partner can keep his/her local copy of profiles of other partners or he/she may request the information if needed. Semiprivate information, as well as information that is updated dynamically (like available capacities), is always stored locally and the owner of this information can decide whether or not to provide it.

Access to information is based on roles – only the responsible agents are authorised to edit it and the others may only read them (if authorised) or do not have access to the information at all. If some information is expected to be out of date, the corresponding partner or information source is asked for an update of the information. The semiprivate information is exchanged in a P2P manner to improve privacy and reduce the impact of some agent failure.

The e-Cat consists of the following subsystems (see Figure 4):

- *Members' registration authority* – allows the full control of members entering or leaving a collaborative network and maintains information for member identification.
- *Catalogue of competency classes* – defines the competencies that can be advertised, their exact descriptions, taxonomy and attributes. It ensures coherence in the common schema of competency.
- *Distributed profile catalogue* – keeps, manages and distributes members' profiles. Each member is responsible for the distributed part of his/her profile.

The presented architecture preserves the members' autonomy and protects semiprivate knowledge. The single point of failure risk is also minimised. When a centralised service fails, the system is still able to operate, but the public information cannot be updated (e.g., profiles, competency structures). The failure of a member agent means excluding this agent temporarily from the VO formation process, but the rest of the system operates normally.

Figure 4 The e-Cat architecture (see online version for colours)

4.1.1 Members' registration authority

The members' registration authority enables members to join the community and maintains the basic information about them. The authority also maintains contact and identification information, which is used to authorise each network member. Therefore, it prevents anonymous users from advertising data via the catalogue and network members from advertising false data on behalf of other members. The members' registration authority is under the control of a subject (*e.g.*, network manager) entrusted by the network.

Each record of the members contains information to be used by a human user and the e-Cat system. The record is divided into two parts:

- 1 member identification that is essential for the e-Cat system and can be edited only by network management (identification contains the name of the company, postal address and e-Cat contact information)
- 2 additional contact information (phone and fax numbers, addresses of websites and e-mails) that can be edited by the owner of the profile.

4.1.2 Catalogue of competency classes

The catalogue of competency classes contains a list of all the competency classes and the relations among them. The classes are organised in a heterarchical structure to enable the definition of generalisations and specialisations of individual competencies. The catalogue of competency classes is maintained by a 'competency expert' of the network management, who is responsible for the clear definition of classes. The competency expert can create, edit and remove competency classes and search and navigate in the database of competency classes. The network members can download whole databases of classes and search and navigate within it.

4.1.3 Distributed profile catalogue

Each component of the competency profile represents one network member and is responsible for the master copy of members' profiles. It also communicates with the members' registration authority in order to keep social knowledge (identification and communication details of other network members) up to date and with the catalogue of competency classes to keep the actual competency database. Whenever the local profile is updated, it is made available to all known network members. If some information (member database, competency database, profile of some member) is expected to be out of date, the particular partner is queried for the data. The members have read-write access to their own profiles and read-only access to other profiles.

The installation and maintenance of the distributed profile catalogue components are mutually independent and (if required) they are independent from the represented network member, too. The members may either maintain this part of their profiles by themselves or they are allowed to hire experts for this purpose and use it only to search for partners.

The distributed profile catalogue is primarily intended to be deployed on members' servers. Moreover, members can also share servers (the location of physical equipment is irrelevant) to install their parts of the distributed profile catalogue. A specialised part of the distributed profile catalogue may be instantiated on a server of the network management to summarise information and represent the profile of the network as a whole.

4.2 Usage scenario

Let us assume a hypothetical, but realistic, scenario in that company 'Dirk Gently' is an SME specialised in transport and sale services and is willing to join a collaborative network. The company contact information will be added to the e-Cat and the company competencies are put into the profile to be available to other members. Thanks to the e-Cat, a member looking for services offered by 'Dirk Gently' is able to find it and contact the company.

- *Joining the e-Cat community and creating a new profile* – as a first step, 'Dirk Gently' installs an e-Cat on the server and configures it to be able to connect to the members' registration authority and catalogue of competency classes. After that, the expert of the members' registration authority creates a new record in the register and adds basic contact information to it.
- *Announcing a competency* – if Dirk Gently decides to offer some services to other network members, the competency class for each service is instantiated in its profile. The appropriate competency classes are found in the catalogue of competency classes. If the proper class does not exist in the catalogue, either a generalising competency is used or the catalogue expert is asked to add a new class to the catalogue. If a request to add a new competency class to the catalogue appears, the competency expert reviews the request and decides whether to accept it and adapt the catalogue or not.
- *Looking for a provider of a competency* – the search engine of the e-Cat information system offers various attributes for finding potential partners among the e-Cat users. If the search result is unsatisfactory, the user can decide to use the taxonomy to find

a generalising or specialising competency and search profiles for them. The first search looks for the available partners with instantiated competencies of closeness to a searched competency equal to zero. Next, the closeness constraint is relaxed until a suitable partner is found.

4.3 Extensions of the tool

There are two ways to include new functionality (*e.g.*, connection to other systems for VO management support or profiles and competencies management) to the e-Cat. In both, the new functionality may be provided by an agent, which is added into the agent community of the e-Cat. At first, an agent with a required functionality should be created. On the other hand, if a network is already using such a system, it may be agentified – there is a new agent created to serve as an interface between the other agents in e-Cat and the legacy system.

5 Pilot implementations

There are two prototype implementations of the e-Cat architecture. They were developed for the following projects:

- *ECOLEAD*⁶ – the original e-Cat prototype for partners' profiles and competencies management within VBE
- *PANDA*⁷ – the tool for partners' competencies catalogue for networks forming Request-Based Virtual Organisations (RBVO) in the Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM) domain.

In *ECOLEAD*, the roles of e-Cat are to (i) maintain the competencies and profiles of the network members and (ii) search for the potential collaborators. In the e-Cat, the agents act roles of the members' models and partially representatives. The system has been verified using three different network datasets. The first dataset has been acquired from *Virtuelle Fabrik*⁸ and used for the verification of the architecture on real data. The second dataset has extended the first one and has been used for a presentation of all the features of the system. The third dataset has been provided by a network organised by Integration Engineering and Construction Systems (IECOS).⁹ *Virtuelle Fabrik* and IECOS evaluated the pilot implementation of e-Cat in daily use.

In *PANDA*, the agents operate on the extra-enterprise level as representatives and assistants of the ERP/CRM network. The e-Cat concept (built on web services) is employed in a VO creation system for semi-automated VO formation process negotiation. A human user of the system manages the classes; the agents search them and select the potential VO members based on the closeness of individual partners' competencies according to the defined requirements. The selected potential partners' agents are involved in the negotiation process that leads to possible VO team configurations.

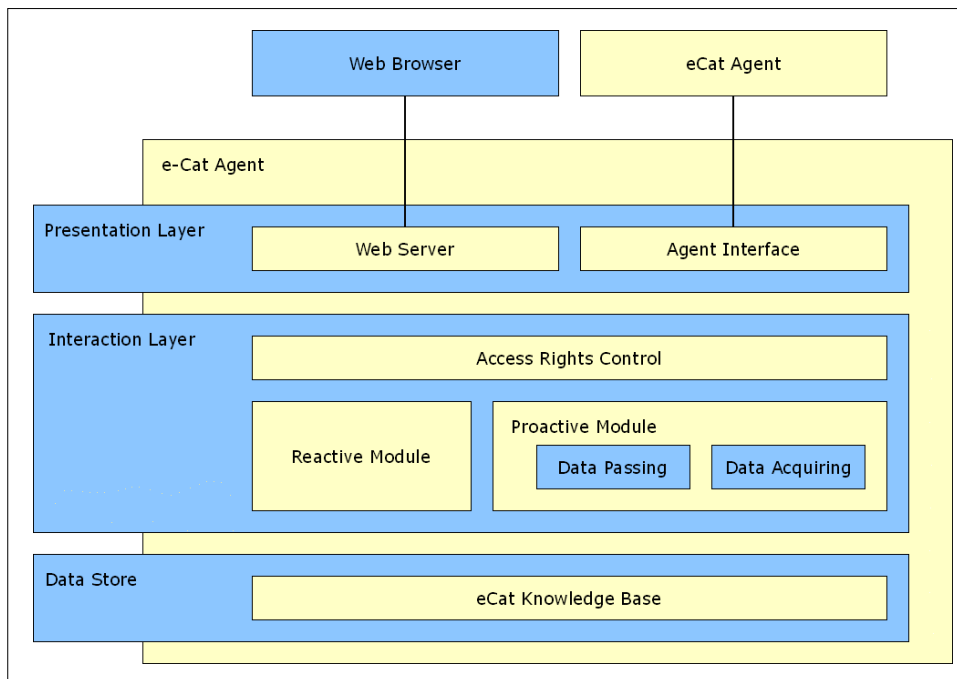
5.1 Implementation details

Here, the pilot implementation for the ECOLEAD project is described because on that implementation, the e-Cat concept was initially proved. The PANDA implementation has been derived from the former one. The implementation is a distributed system based on a multi-agent architecture.

The prototype design of all agents (representing the members' registration authority, catalogue of competency classes, and all components of the distributed profile catalogue) in the e-Cat system covers the whole three-tier model (see Figure 5). It contains two data presentation interfaces: (i) interface for interagents' negotiation and cooperation and (ii) web-based interface for interaction with human users. A security module provides access to reactive and proactive modules for data passing (data provision on the request of another agent) and acquiring (for requesting data from another agent). The general knowledge storage base in the data storage layer is provided by proprietary data storage.

The e-Cat is based on the Enterprise-to-Enterprise (E2E) technology developed for projects ExPlanTech and ExtraPlanT (Hodík *et al.*, 2005) as a technology to support extra enterprise cooperation and collaboration. The system is implemented in Java language. The multi-agent part of the system is implemented using the Java Agent Development Framework (JADE)¹⁰ multi-agent platform (Bellifemine *et al.*, 1999). All user interfaces in the system are implemented as web-based thin clients.

Figure 5 The architecture of the e-Cat agent (see online version for colours)



6 Conclusion and future work

At first, support for partners' profiles and competency management has been presented. The results of this part are applicable before VO formation, when a network member intends to be included in network information resources to be later found as a potential partner, during the VO formation process when the competent VO members should be identified and during the VO evolution, when the VO team has to be extended by new members.

The impact is on structuring the competencies, the architecture of the system for competencies and profiles management, as well as a prototype proving these concepts. The architecture follows a naturally hybrid character of networks that consists of mutually independent network partners who may be supported by central institutions' components. As the individual enterprises organised in the network are independent, they may require managing their profiles by themselves – this is a very important feature given by the requirements of information privacy. The central components are inherited from the architecture of networks (*e.g.*, networks or VBEs) that are formed by companies in order to facilitate formations of VOs.

The main ideas presented in this paper are the following:

- *Definition of the consistent terminology* – the paper provides definitions of the profile and competency-related terms and how they mutually relate. Then, relation links between competencies were defined, as well as various types of competencies structures. Basic methods for searching in the structures were introduced.
- *Hybrid architecture* – this architecture is patterned after the structure of networks of SMEs. It contains independent units representing individual partners as well as centralised network services.
- *Catalogue of competency classes* – this catalogue provides a common language for competencies description and facilitates the search for potential partners during the VO formation process, as well as during VO reconfiguration.
- *Multi-agent technology* – each unit participating on the e-Cat is represented by a single independent agent, which is fully under control of the unit. It allows a clear distribution of responsibility, as well as full control of the unit over their data in e-Cat.
- *Pilot implementation of the concept* – the concept of competency and related structures is utilised in e-Cat, which is a concept (and its pilot implementation) of a member profiling and competency management tool.

The strong points of the presented concepts and tools are the preservation of the members' autonomy, semiprivate knowledge protection and single point of failure risk minimisation. These features are essential to be addressed in today's e-business environment.

The future work is in extending the partners' profiles and competencies management system by having access to the intra-enterprise scheduling systems (similarly to extra-enterprise scheduling and the coordination tool ExtraPlanT) and the interconnection of this extended system with the systems for VO operational management. By that, a tool for semi-automated creation, monitoring and adaptation would be created.

The system can be also extended by introducing the concept of competencies composed of several basic subcompetencies. If all the requested subcompetencies are present, their holder or group of holders is considered as having the ‘composed competency’; even so, none of the group members alone has all the necessary subcompetencies. These extensions would also benefit from a ‘catalogue of resource classes’ defining a common understanding of resources’ types, as well as their skills and capacity. Such a catalogue is not present in the architecture yet. The first steps have been already done for the PANDA project, where an extended approach has been used in order to build a semi-automated tool for negotiation about VO team formation during its creation.

Acknowledgement

The work is (partly) funded by the European Commission’s FP6 programme within the projects ECOLEAD (contract NO. FP6 IP 506958), PANDA (contract NO. 027169) and I*PROMS Network of Excellence and the Ministry of Education.

Any opinions expressed in this paper do not necessarily reflect the views of the European Community. The Community is not liable for any use that may be made of the information contained herein.

References

- Adesta, E.Y.T. (2005) ‘A strategic planning procedure to support progress towards extended enterprise’, in K.S. Pawar, F. Weber, K-D. Thoben and B. Katzy (Eds.) *Proc. of the 11th Int. Conf. on Concurrent Enterprising ICE-2005*, Centre for Concurrent Enterprising, pp.371–377.
- Bellifemine, F., Rimassa, G. and Poggi, A. (1999) ‘JADE – A FIPA-compliant agent framework’, *Proceedings of 4th International Conference on the Practical Applications of Intelligent Agents and Multi-Agent Technology*, London.
- Biesalski, E. (2003) ‘Knowledge management and e-human resource management’, *FGWM 2003*, Karlsruhe.
- Browne, J. and Zhang, J. (1999) ‘Extended and virtual enterprises – similarities and differences’, *International Journal of Agile Management Systems*, Vol. 1, No. 1, pp.30–36.
- Camarinha-Matos, L.M. and Afsarmanesh, H. (2004) *Collaborative Networked Organizations: A Research Agenda for Emerging Business Models*, Kluwer Academic Publishers, pp.3–10.
- Capó, J., Lario, F.C. and Ortiz, A. (2004) ‘Proposal of an advanced model for supply chain management in construction industries, based on the virtual enterprise’, in K-D. Thoben, K.S. Pawar and F. Weber (Eds.) *Proc. of the Tenth Int. Conf. on Information and Computation Economics ICE-2004*, Centre for Concurrent Enterprising, pp.395–402.
- Faisst, W. (1997) ‘Information technology as an enabler of virtual enterprises: a life-cycle-oriented description’, *Proceedings of the European Conference on Virtual Enterprises and Networked Solutions*, Paderborn, Germany.
- Fischer, K., Müller, J.P., Heimig, I. and Scheer, A-W. (1996) ‘Intelligent agents in virtual enterprises’, *Proceedings of the First International Conference on the Practical Application of Intelligent Agents and Multi Agent Technology (PAAM)*, Blackpool, UK, pp.205–223.

- Friese, T., Freisleben, B., Rusitschka, S. and Southall, A. (2003) 'A framework for resource management in peer-to-peer networks', in M. Aksit, M. Mezini and R. Unland (Eds.) *Objects, Components, Architectures, Services, and Applications for a Networked World, International Conference NetObjectDays, NODe 2002, Erfurt, Germany, October 7–10, 2002, Revised Papers*, Volume 2591 of Lecture Notes in Computer Science, Springer, pp.4–21.
- Friese, T., Müller, J.P., Smith, M. and Freisleben, B. (2005) 'A robust business resource management framework based on a peer-to-peer infrastructure', *Proceedings of 7th IEEE International Conference on E-Commerce Technology (CEC 2005)*, IEEE Computer Society, pp.215–222.
- Gruber, M. and Nöster, M. (2005) 'Investigating structural settings of virtual organisations', in K.S. Pawar, F. Weber, K-D. Thoben and B. Katzy (Eds.) *Proc. of the 11th Int. Conf. on Concurrent Enterprising ICE-2005*, Centre for Concurrent Enterprising, pp.245–252.
- Hagel, J., III and Armstrong, A.G. (1997) *Net Gain: Expanding Markets Through Virtual Communities*, HBS Press.
- Hamel, G. and Prahalad, C.K. (1990) 'The core competence of the corporation', *Harvard Business Review*, Vol. 68, No. 3, pp.79–91.
- Hodík, J., Bečvář, P., Pěchouček, M., Vokřínek, J. and Pospíšil, J. (2005) 'ExPlanTech and ExtraPlanT: multi-agent technology for production planning, simulation and extra-enterprise collaboration', *International Journal of Computer Systems Science and Engineering*, Vol. 20, No. 5, pp.357–367.
- Hodík, J., Vokřínek, J. and Bečvář, P. (2008) 'e-Cat for partner profiling and competency management tool', *Encyclopedia of Networked and Virtual Organizations – vol. I A-F*, Hershey: Information Science Reference, Vol. 1, pp.452–458.
- Konsynski, B.R. (1993) 'Strategic control in the extended enterprise', *IBM Systems Journal*, Vol. 32, No. 1, pp.111–142.
- Lemaignan, S., Siadat, A., Dantan, J-Y. and Semenenko, A. (2006) 'MASON: a proposal for an ontology of manufacturing domain', in V. Mařík, W.A. Gruver, M. Pěchouček and L. Přeučil (Eds.) *IEEE Workshop on Distributed Intelligent Systems: Collective Intelligence and Its Applications (DIS'06)*, Los Alamitos, CA: IEEE Computer Society, pp.195–200.
- Linn, C. (1999) 'A multi-agent system for cooperative document indexing and querying in distributed networked environments', *ICPP Workshops*, pp.400–405.
- Mařík, V. and Pěchouček, M. (2004) 'Agent technology', in L.M. Camarinha-Matos and H. Afsarmanesh (Eds.) *Collaborative Networked Organizations: A Research Agenda for Emerging Business Models*, Kluwer Academic Publishers, pp.193–206.
- Masaud-Wahaishi, A., Ghenniwa, H. and Shen, W. (2003) 'Brokering services in cooperative distributed systems: privacy-based model', in K. Bauknecht, A.M. Tjoa and G. Quirchmayr (Eds.) *E-Commerce and Web Technologies, 4th International Conference, EC-Web, Prague, Czech Republic, September 2–5, 2003, Proceedings*, Vol. 2738 of LNCS, Springer, pp.435–444.
- Molina, A., Flóres, M. and Caballero, D. (1998) 'Virtual enterprises: a Mexican case study', in L.M. Camarinha-Matos, H. Afsarmanesh and V. Mařík (Eds.) *Intelligent Systems for Manufacturing: Multi-Agent Systems and Virtual Organizations, Proceedings of the BASYS – 3rd IEEE/IFIP International Conference on Information Technology for Balanced Automation Systems in Manufacturing, Prague, Czech Republic, August 1998*, Vol. 130 of IFIP Conference Proceedings, Kluwer, pp.159–170.
- Neubert, R., Langer, O., Görlitz, O. and Benn, W. (2001) 'Virtual enterprises-challenges from a database perspective', *ITVE '01: Proceedings of the IEEE Workshop on Information Technology for Virtual Enterprises*, Washington, DC: IEEE Computer Society, pp.98–106.
- Norman, T.J., Preece, A.D., Chalmers, S., Jennings, N.R., Luck, M., Dang, V.D., Nguyen, T.D., et al. (2004) 'Agent-based formation of virtual organisations', *Knowl.-Based Syst.*, Vol. 17, Nos. 2–4, pp.103–111.
- Oren, N., Preece, A. and Norman, T. (2005) 'Service level agreements for semantic web agents', *Proc. AAAI Fall Symposium on Agents and the Semantic Web*, pp.47–54.

- Patel, J., Teacy, W.T.L., Jennings, N.R., Luck, M., Chalmers, S., Oren, N., Norman, T.J., *et al.* (2006) 'CONOISE-G: agent-based virtual organisations', in H. Nakashima, M.P. Wellman, G. Weiss and P. Stone (Eds.) *5th International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS 2006), Hakodate, Japan, May 8–12, 2006*, ACM, pp.1459–1460.
- Petersen, S.A., Divitini, M. and Matskin, M. (2001) 'An agent-based approach to modelling virtual enterprises', Special issue 'Enterprise modeling', *International Journal of Production, Planning and Control*, Vol. 12, No. 3, pp.224–233.
- Preece, A., Hui, K. and Gray, P. (1999) 'Kraft: supporting virtual organisations through knowledge fusion', *Artificial Intelligence for Electronic Commerce: Papers from the AAI-99 Workshop*, AAAI Press, pp.33–38.
- Říha, A., Pěchouček, M., Vokřínek, J. and Mařík, V. (2002) 'From intra-enterprise towards extra-enterprise production planning', in V. Mařík, L.M. Camarinha-Matos and H. Afsarmanesh (Eds.) *Knowledge and Technology Integration in Production and Services: Balancing Knowledge in Product and Service Life Cycle, IFIP TC5/WG5.3 Fifth IFIP/IEEE International Conference on Information Technology for Balanced Automation Systems in Manufacturing and Services (BASYS'02), September 25–27, 2002, Cancun, Mexico*, Vol. 229 of IFIP Conference Proceedings, Kluwer, pp.349–356.
- Rocha, A.P. and Oliveira, E. (2001) 'Electronic institutions as a framework for agents' negotiation and mutual commitment', in P. Brazdil and A. Jorge (Eds.) *EPIA 2001*, LNAI 2258, Springer-Verlag Berlin Heidelberg, pp.232–245.
- Schmees, M. (2003) 'Distributed digital commerce', in N.M. Sadeh, M.J. Dively, R.J. Kauffman, Y. Labrou, O. Shehory, R. Telang and L. Cranor (Eds.) *Proceedings of the 5th International Conference on Electronic Commerce, ICEC 2003, Pittsburgh, Pennsylvania, USA, September 30 – October 03, 2003*, ACM, pp.131–137.
- Shao, J., Gray, W.A., Fiddian, N.J., Deora, V., Shercliff, G., Stockreisser, P.J., Norman, T.J., *et al.* (2004) 'Supporting formation and operation of virtual organisations in a grid environment', *Proceedings of the UK e-Science All Hands Meeting (AHM)*, pp.376–383.
- Sheth, A.P. and Larson, J.A. (1990) 'Federated database systems for managing distributed, heterogeneous, and autonomous databases', *ACM Comput. Surv.*, Vol. 22, No. 3, pp.183–236.
- Van Wijk, J., Geurts, D. and Bultje, R. (1998) '7 steps to virtuality: understanding the virtual organization processes before designing ICT support', *Objects, Components and the Virtual Enterprise '98. An interdisciplinary workshop*, <http://www.cs.tcd.ie/Virtues/ocve98/proceedings/index.html>.
- Voos, H. (2006) 'Agent-based distributed resource allocation in technical dynamic systems', in V. Mařík, W.A. Gruver, M. Pěchouček and L. Přeučil (Eds.) *IEEE Workshop on Distributed Intelligent Systems: Collective Intelligence and Its Applications (DIS'06)*, Los Alamitos, CA: IEEE Computer Society, pp.157–162.
- Wiendahl, H-P. and Lutz, S. (2002) 'Production in networks', *CIRP Annals – Manufacturing Technology*, Vol. 51, pp.573–586.
- Yan, J., Yang, Y. and Raikundalia, G.K. (2006) 'SwinDeW-a p2p-based decentralized workflow management system', *IEEE Transactions on Systems, Man, and Cybernetics Part A – Systems and Humans*, Vol. 36, No. 5, pp.922–935.
- Yang, Y. (2000) 'An architecture and its related mechanisms for web-based global cooperative teamwork support', *Informatica*, Vol. 24, No. 1, pp.13–19.

Notes

- 1 CVS version control system description, <http://www.nongnu.org/cvs/>.
- 2 SVN version control system description, <http://subversion.tigris.org/>.
- 3 Git – Fast Version Control System, Git version control system description, <http://git.or.cz/>.

- 4 NASA Office of Human Capital Management, NASAPeople specifications, <http://nasapeople.nasa.gov/>.
- 5 HR-XML consortium, platform for development of human resources XML vocabularies, <http://www.hr-xml.org/>.
- 6 European Collaborative Networked Organisations LEADership (ECOLEAD) initiative, <http://www.ecolead.org/>.
- 7 PANDA, Collaborative Process Automation Support using Service Level Agreements and Intelligent dynamic Agents in SME clusters, <http://www.panda-project.com/>.
- 8 Virtuelle Fabrik AG, VF network description, <http://www.virtuelle-fabrik.com/>.
- 9 IECOS network description, <http://www.iecos.com/>.
- 10 JADE, <http://jade.tilab.it/>.