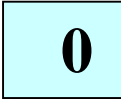V. Dignum, F. Dignum, Towards an agent-based infrastructure to support virtual organisations, Proceedings of PRO-VE'02 - IFIP Int. Conf. on Infrastructures for Virtual Enterprises (L.M. Camarinha-Matos, Ed.), 1-3 May 2002, Sesimbra, Portugal. (to be published by Kluwer Academic Publishers)

0	**TOWARDS AN AGENT-BASED INFRASTRUCTURE TO SUPPORT VIRTUAL ORGANISATIONS**

Virginia Dignum [1, 2], Frank Dignum[2]

[1] Achmea
P.O. Box 866, 3700 AW Zeist, The Netherlands
virginia.dignum@achmea.nl

[2] University Utrecht
Institute for Information and Computing Sciences
PO Box 80.089, 3508TB Utrecht, The Netherlands
{virginia, dignum}@cs.uu.nl

In this paper, we present a framework for the support of virtual organisations based on agent societies. As in human societies, we argue that norms and institutions are a way for agent societies to cope with the challenge of social order. Institutions are used to implement and monitor the conventions, norms and goals of the virtual organisation.

1. INTRODUCTION

The formation and operation of dynamic and open virtual organisations (VO) is a central concern in modern business. Virtual organisations can be seen as environments where partners dynamically come together in response to or in anticipation of new market opportunities that require a combination of strengths, skills, resources, risks and finances no partner can alone fulfil. VO's enable partner companies to develop and produce customised products, services or combinations of both, with low costs and rapid delivery.

Virtual organisations are characterised by their loose structure, lack of hierarchy and their empowered and geographically dispersed members. Challenges to the development of virtual organisations are therefore the handling of distributed management, knowledge and data; the integration of different cultures, processes and methods; the need to provide just in time, personalised services and products in a changing environment under unknown influences. Furthermore, because members work rather individually with hardly any centralised control and often are difficult to motivate and suffer from social loafing and absenteeism, VO's are difficult to manage (Bosch-Sijstema, 2001). These factors imply that virtual organisations cannot be specified a priori but design has to be able to cope with changes in structure, aims and environment conditions.

Even though many parts of a VO can change over time, the VO is formed for a specific purpose and its organisation must fit this purpose. Organisation theory shows that organisations with collaboration, exchange or production objectives are co-ordinated differently (Nouwens and Bouwman, 1995). For example, the market model fits well an exchange organisation, and the hierarchical model can be used in production settings. Co-ordination models describe issues such as communication forms, desired social order and co-operation possibilities between partners. Models of virtual organisations must therefore consider co-ordination issues such as co-operation and social order. The modelling and support of VO's calls for methods and frameworks that support co-ordination in open environments, enforce agreed norms and rules and contribute to a sense of trust by the participants.

Software agents are characterised as autonomous entities with reasoning and communicative capabilities, and are therefore, utmost suitable to implement, simulate or represent real-life entities presenting the same autonomy. Because of the proactive and autonomous behaviour of agents it is natural to design agent societies mimicking the behaviour and structure of human organisations (Zambonelli et al., 2001). Multi-agent systems, or agent societies, are increasingly being considered a viable technological basis for implementing complex, open systems that support virtual organisations. Previous work shows that agent societies are an effective platform for virtual organisations because they provide mechanisms that allow organisations to advertise their capabilities, negotiate their terms, exchange rich information, and synchronise processes and workflow at a high-level of abstraction (Preece et al., 1999).

In this paper we argue that agent societies and the use of norms and institutions to cope with the challenge of social order are a suitable and practical framework for the development and support of VO's. In one hand, modelling VO's as agent societies facilitates and guides the design and verification of the VO. On the other hand, during the 'life time' of the VO, agent societies can use to support interaction between partners and exchange of information. These concepts and methods are currently applied to the development of practical applications at Achmea.

2. ORGANISATIONAL MULTI-AGENT SYSTEMS

Virtual organisations, as all organisations, can be seen as sets of entities regulated by mechanisms of social order and created by more or less autonomous actors to achieve common goals. Business processes are essentially interactions between actors and therefore can be effectively modelled using multi-agents systems. In organisational settings, agents are more and more seen as useful modelling abstractions that can be used at different logical levels in the modelling of organisations, instead of mere technological building blocks (Taveter, 2001).

In business environments, the behaviour of the global system and the collective aspects of the domain, such as stability over time, predictability and commitment to aims and strategies, must be considered. Organisations are expected to form a coherent and stable system that realises the objectives for which it was designed. When multi-agent systems, or **agent societies**, are considered from an organisational point of view, the concept of desirable social behaviour becomes of utmost importance. From the organisational point of view, the behaviour of individual agents in a society should be understood and described in relation to the social

structure and overall objectives of the society. However, until recently, multi-agent systems are mainly viewed from an individualistic perspective, that is, as aggregations of agents that interact with each other (Ferber and Gutknecht, 1998). In this view the behaviour of multi-agent system is seen from the perspective of the agent itself, in terms of how an agent can affect the environment or be affected by it.

In order to apply multi-agent systems for the modelling and support of virtual organisations, the specific characteristics of such organisations must be considered. An important aspect is that virtual organisations are open societies consisting of independently developed components and actors that may change, join or leave the virtual organisation over time, while the organisation still fulfils its original purpose. This implies that agent societies modelling virtual organisations cannot be designed based solely on the internal architectures of its members. The specific structure of the organisation determines the relationships in the conceptual model of the agent society and the main co-ordination mechanisms that are used to support the activities of the virtual organisation. Multi-agent systems that model and support virtual organisations should therefore be based on co-ordination frameworks that explicitly describe the structure of the particular organisation and are able to dynamically adapt to changes in organisation structure, aims and interactions. From the above considerations we have distilled the following requirements for any formalism for the design of agent societies that are used to model and support VO's (Dignum and Dignum, 2001):

- Include formalisms for the description, construction and control of the organisational and normative elements of a society (roles, norms and goals) instead of just agent states.
- Provide mechanisms to describe the environment of the society and the interactions between agents and the society, and to formalise the expected outcome of roles in order to verify the overall animation of the society.
- Explicitly specify the organisational and normative elements of the society since an open society cannot rely on its embedding in the intentions, desires and beliefs of each agent.
- Provide methods and tools to verify whether the design of an agent society satisfies its design requirements and objectives.
- Provide building directives concerning the communication capability and ability to conform to the expected role behaviour of agents in the society.

2.1. The role of institutions

Usually human organisations and societies use norms and conventions to cope with the challenge of social order. Norms and conventions specify the behaviour that society members are expected to conform to and are suitable for decentralised control. In most societies, norms are backed by a variety of social institutions that enforce law and order (e.g. courts, police), monitor for and respond to emergencies (e.g. ambulance system), prevent and recover from unanticipated disasters (e.g. coast guard, fire-fighters), etc. In this way, citizens of civilised societies can utilise relatively simple and efficient rules of behaviour, offloading the prevention and recovery of many problem types to social institutions that can handle them efficiently and effectively by virtue of their economies of scale and widely accepted legitimacy. Successful civil societies have thus achieved a division of labour between individuals and institutions that decreases the "barriers to survival" for each

citizen, while helping increase the welfare of the society as a whole (Workshop Norms and Institutions, 2001).

Several researchers have recognised that the design of agent societies can benefit from abstractions analogous to those employed by our robust and relatively successful societies and organisations. A growing body of work touches upon the concepts of norms and institutions in the context of multi-agent systems (cf. Dignum, 2001, Esteva et al., 2001). The virtue of an institution resides in its potential to lend legitimacy to its members and security to its traders by establishing norms. The electronic counterpart of the physical institution does a similar task for software agents: it can engender trust through certification of an agent and by the guarantees that it provides to back a trade. That is, institutions enable to:

- Specify co-ordination structure used
- Describe exchange mechanisms of the VO
- Determine interaction and communication forms within the VO
- Facilitate the perception of individual agent of the aims and norms of an agent society
- Enforce organisational aims of the agent society

A less obvious virtue of an institution is that it also defines the kinds of transactions that can take place. Looking at the structure of organisations we can anticipate the types of interaction involved in trading in a particular institution (consider a shop, versus an auction, versus a market). Thus, an institution defines a performative structure and a dialogical framework, by which we mean, it prescribes the actions members can take and when and where to perform those actions. The form of conversations between members is to a certain extent also determined at the institution level.

Different organisation types rely on different institutional forms to enforce and organise social interactions between its member through values, norms and sanctions. Institution models provide standard ways to describe relational forms and social norms within societies. Institutions can link the objectives of agents and the goals of the society. Our framework provides standard models of institutions based on the co-ordination requirements of the domain that can be used as a basis for the development of agent societies.

2.2. Co-ordination Frameworks

The way organisations are organised is determining to the development of agent societies since different application contexts and requirements for virtual organisations will exhibit different needs with respect to co-ordination. The organisation model determines the important co-ordination activities, which must be explicitly organised into the conceptual model of the agent society (Dignum et al., 2001). As described before, the design of organisation-oriented multi-agent systems must account for the representation and management of normative aspects of the society and incorporate collective characteristics of an organisation such as stability over time, some level of predictability, and clear commitment to aims and strategies. The agent society model we propose consists of two layers. The facilitation or **institutional layer** provides the social and institutional backbone of the society, is determined by the type of co-ordination holding in the society and is based on the

concepts of norms and institutions. The **operational layer** models the overall objectives and intended action of the society and is domain dependent.

Following the basic classification of co-ordination models from organisational theory, agent societies can be divided into markets, networks and hierarchies. Each co-ordination model determines a different institutional framework for agent societies. The institutional layer must describe institutional roles, the way interactions between roles are organised and the way the interface between the society and the 'outside world' is defined. Facilitation activities deal with the functioning of the society itself and are dependent on the underlying co-ordination model and on the norms and conventions that hold on the domain. Social co-ordination describes the way interactions between agents are organised and the way the interface between the society and the 'outside world' is defined. That is, the co-ordination model determines the institutional roles, social norms and interaction forms in the society.

In **markets**, agents are self-interested (determine and follow their own goals) and value their freedom of association and own judgement above security and trust issues. Openness is thus per definition a feature of markets. Facilitation is, in the most extreme case, limited to identification and matchmaking activities. Interaction in markets occurs through communication and negotiation.

Network organisations are built around general patterns of interaction or contracts. Relationships are dependent on clear communication patterns and social norms. Agents in a network society are still self interested but are willing to trade some of their freedom to obtain secure relations and trust. Therefore, agents need to enter a social contract with the network society in which they commit themselves to act within and according to the norms and rules of the society. The society is responsible to make its rules and norms known to potential members. Co-ordination is achieved by mutual interest, possibly using trusted third parties, and according to well-defined rules and sanctions.

Finally, in a **hierarchy** interaction lines are well defined and the facilitation level assumes the function of global control of the society and co-ordination of interaction with the outside world. In a hierarchy, agents are co-operative, not motivated by self interest and all contribute to a common global goal. Co-ordination is achieved through command and control lines. Agents are co-operative and not motivated by self-interest. Table 1 gives an overview of the characteristics of agent societies with different co-ordination models.

Table 1 - Characteristics of agent societies

	Market	**Network**	**Hierarchy**
Type of society	Open	Trust	Closed
Members 'values'	Self interest	Mutual interest/ Collaboration	Dependency
Society purpose	Exchange	Collaboration	Production
Interaction	Interaction is based on standards; communication concerns exchange only	Both the interaction procedures and exchange can be negotiated	Specified on design

The characteristics and requisites for each role determine the required capabilities of agents fulfilling the role in terms of its communicative and reasoning capabilities. For example, agents acting in a network are expected to negotiate their interaction procedures and are motivated by mutual interest. This means such agents will be required to be able to reason about other agents and need to possess 'heavy' negotiation algorithms. On the other hand, members of a hierarchical society follow pre-determined communication lines and have limited need for negotiation, thus agents fulfilling hierarchical roles can be much simpler in terms of communication and negotiation capabilities.

3. APPLICATIONS

The framework described in this paper can be applied to very distinct problem domains, because it concentrates on the organisational elements of the agent societies that support the resulting VO. At Achmea, a large financial and insurance organisation operating mainly in the Netherlands, the ideas described in this paper are being applied to the development of different virtual organisations as described below.

3.1. Knowledge Exchange Network

We are currently applying the methodology described in this paper to the development of a system that supports knowledge exchange between non-life insurance experts. Business units and daughter companies of Achmea operated quite autonomously, with different business strategies and goals. Therefore co-operation between them can be seen as a virtual enterprise. The Knowledge Exchange Network preserves existing knowledge, rewards knowledge owners and reaches knowledge seekers in a 'just in time, just enough' basis. The network will serve both as a knowledge repository as well as a means for support and encouragement of communication and collaboration. In this section we briefly describe the aims of an agent society being developed to model the knowledge sharing activities. In this domain, both knowledge seekers and knowledge owners want to be able to decide on trade partners and conditions. Sharing is not centrally controlled but greatly encouraged by the management. The best-suited partner, according to each participant's own conditions and judgement, will get the 'job'. Factors such as privacy, secrecy and competitiveness between brands and departments may influence the channels and possibilities of sharing and must thus be considered.

The requirements for the system identify a distributed system where different actors, acting autonomously on behalf of users and each pursuing its own goals, need to interact in order to achieve their goals. Communication and negotiation are paramount. Furthermore, the number and behaviour of participants cannot be fixed a priori and the system can be expected to expand and change during operation, both in number of participants as in amount and kind of knowledge shared. Participants in the network are aware of and collaborative with this requirement but also have their own objectives and constraints. Participants wish to be free to determine their own exchange rules and to be assured that participation in the environment is controlled.

Due to space limitations, we cannot describe the complete system in this paper. In the following we will explain the choice of co-operation model and describe some of the roles and interactions. In the situation described above a market framework is

not really suitable because negotiation in a market follows fixed rules that participants must follow. Moreover, participation is open to any agent, and restriction of role or access is not possible. Also the hierarchical model can be rejected because it imposes a fixed partnership relation that is not possible, since partners and sources are not a priori known.

The requirements of stakeholders point to a situation where the network model is most appropriate. The roles of matchmaker, notary, monitor, and gatekeeper follow naturally from the choice of a network structure. From the domain requirements the roles of knowledge owner and knowledge seeker can be deduced. The 'goods' to be exchanged are the contents of the knowledge repository, that is, (XML) documents representing knowledge about reports, people, applications, web sites, projects, questions, etc. The institution underlying the society imposes specific mechanisms for collaboration and certification. For instance, in the knowledge network a special kind of knowledge owner is responsible for the gathering and dissemination of information about a known, fixed list of subjects to knowledge seekers that subscribed to it. The institution must enforce the norm that such agents are required to provide all the information they are aware of. This determines a task for the monitors tracing this type of contracts of checking if information in all subjects in the list is indeed provided.

3.2. Care Market

Other plans for application this framework include the development of a mediation system in the area of secondary healthcare co-ordination (CareMarket). The aim of CareMarket, a community care project, is to provide Achmea clients with extra (unskilled) care services, which are not covered by professional organisations, or for which there are long waiting lists. The project is inspired by the LETS concept and based on non-monetary trading concepts. Matching of supply and demand in this kind of situations is not trivial. The fulfilment of a demand usually requires the co-ordination of several suppliers, suppliers are voluntaries and usually of a very limited and constrained range of services. Furthermore, it is desirable to keep a continuity of relationships between suppliers and clients (people tend to develop friendship relations with their care tenders / care takers and do not really appreciate to see a new face every day). An agent society will provide a platform to the formation of virtual enterprises matching the possibilities and preferences of care providers with the specific needs of care seekers. Both care seekers as care providers will be represented by agents and can join or leave the society and describe their needs and possibilities. The underlying institution will find matches according to agent's profile and within the norms and rules of the society. This pilot is in a very initial phase of development but there is already a clear realisation that the ideas described in this paper will be directly applicable to the development of an agent-based simulation prototype. The evaluation of the system through a simulated institution populated with intelligent agents, representing suppliers and clients, will provide insights and support to the eventual deployment of a real community pilot.

4. CONCLUSIONS AND FUTURE WORK

We have presented arguments for the use of agent societies as an infrastructure for both modelling and supporting virtual organisations. Agent societies should be

based on the co-ordination structure of the domain and use institutions to specify and enforce social norms and conventions. Our approach is to provide a generic frame that directly relates to the organisational perception of a problem. Therefore the proposed frameworks take the organisational perspective as starting point. One contribution of our research is that it shows the implications of the co-ordination model of the virtual organisation for the interactions and information exchange needed to fulfil the overall goal of the VO. If needed, existing methodologies can be used for the development, modelling and formalisation of each step. We believe that our approach contributes to the acceptance of multi-agent technology by organisations.

We also exposed the use of institutions for the co-ordination in VO where the participants act according to their own goals and capabilities. Institutions enforce the global behaviour of the VO and assure that the global goals of the VO are met. Institutions therefore also play an important role to specify and manage the conventions of the agent society supporting the VO. One of the most important aspects is that they can make organisational goals and norms explicit and warrant their fulfilment by providing explicit facilitation roles and controlled interaction protocols. Feedback from the applications currently under development at Achmea will be used to improve the design methodology and the co-ordination frameworks.

5. REFERENCES

1. Bosch-Sijtema, P.: Virtual Organisation and Knowledge Development. A Case of Expectations. In: Proceedings of the ISKO 2001 conference on Wissensorganistion und Edutainment, Berlin, (2001).
2. Dignum, V. Dignum, F.: Modelling agent societies: co-ordination frameworks and institutions. In: Proceedings of Workshop on Multi-agent Systems: Theory and Applications (MASTA), 10th Encontro Português de Inteligência Artificial (EPIA 2001), Porto, Portugal, (2001).
3. Dignum, V., Weigand, H., Xu L.: Agent Societies: Towards framework-based design. In: Wooldridge, M., Ciancarini P., Weiss, G. (Eds.): Proceedings of the 2nd Workshop on Agent-Oriented Software Engineering, Autonomous Agents, Montreal, (2001) 25-31.
4. Dignum, F.: Agents, Markets, Institutions and Protocols. In Dignum, F., Sierra, C. (eds.): Agent Mediated Electronic Commerce, LNAI 1991, Springer-Verlag (2001) 98 – 114.
5. Esteva, M., Padget, J., Sierra, C.: Formalising a language for Institutions and Norms. Proceedings of the 8th International Workshop on Agent Theories, Architectures and Languages, Seattle, (2001)
6. Ferber, J., Gutknecht, O.: A meta-model for the analysis and design of organisations in multi-agent systems. In: Proceedings of the Third International Conference on Multi-Agent Systems (ICMAS'98), IEEE Computer Society, (1998)
7. Nouwens, J., Bouwman H. (1995). Living Apart Together in Electronic Commerce: The Use of Information and Communication Technology to Create Network Organisations. Steinfield, C. (ed.). Journal of Computer Mediated Communication, Special Issue in Electronic Commerce, 1(3).
8. Preece, A., Hui K., Gray, P.: KRAFT: Supporting Virtual Organisations through Knowledge Fusion. In: Finin T., Grosof B. (Eds): AI for E-Commerce Workshop, AAAI Press, (1999) 33-38.
9. Taveter, K.: From Descriptive to Prescriptive Models of Agent-Oriented Information Systems. In: Proceedings of 3rd Workshop on Agent-Oriented Information Systems, Autonomous Agents, Montreal, http://www.aois.org, (2001).
10. Workshop on Norms and Institutions, Call for Papers, Autonomous Agents, Montreal, http://ccs.mit.edu/dell/aa2001, (2001).
11. Zambonelli, F., Jennings, N., Omicini, A., Wooldridge, M.: Agent-Oriented Software Engineering for Internet Applications. In: A. Omicini, Zambonelli, F., Klusch, M., Tolkdorf, R. (eds.): Coordination of Internet Agents: Models, Technologies, and Applications. Springer-Verlag (2001) 326 - 346