A FRAMEWORK FOR MULTI-AGENT MODELLING OF VIRTUAL ORGANISATIONS

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A model of a virtual organisation consisting of hundreds of thousands of intelligent agents has been developed by authors and their collaborators in London, UK and Samara, Russia. The model is based on ontological rather than mathematical description of the organisation and is characterised by the capability of selforganisation and evolution. It is based on the notion that organisations participating in a highly dynamic global economy are structured as networks and behave as complex adaptive systems rather than rigid hierarchies. The model is intended to be used for the design and governance of virtual organisations.

INTRODUCTION

Virtual Enterprises (VE) have been extensively studied for a number of years, as evidenced in recent collections of papers (Camarinha-Matos, Afsarmanesh 1999), (Camarinha-Matos, Afsarmanesh, Rabelo 2000) and (Camarinha-Matos 2002). Nevertheless a number of issues are still left to be resolved, including the issue of networking of constituent organisational units.

The authors have developed a framework for modelling VE, which fundamentally differs from the traditional mathematical and probabilistic approaches. The new model is ontological, that is, it depicts a VE in terms of classes of constituent objects and their attributes, relationships and scripts. The ontological approach produces models that closely mirror the real organisation and preserve its inherent variety and uncertainty. It is of considerable advantage that ontology of a virtual organisation can be built by domain experts without any knowledge of advanced mathematics or computer programming. Once ontology is constructed, the model can be used to evaluate the ability of the VE to meet a given level of demand by its constituent resources. There is a choice of levels of detail that can be incorporated into the model. Software agents can be assigned to groups of demands and resources (eg, a project or a plant), or to each individual demand, such as an order or enquiry, as well as each individual organisational resource (eg, an employee, a manager, a machine, a unit of capital or an element of organisational knowledge). In any case the allocation of resources to demands is accomplished by negotiation between agents representing demands and resources (local or global) rather than by centralised algorithms.

A particular simulation scenario was devised to obtain answers to “what if?” questions of interest to authors, as described in the next section. This scenario is based on well known notions from literature on VE and authors do not claim any credit for its construction. However the agent-based modelling approach described further in this paper is to the best of our knowledge novel. It is highly flexible and could be used for investigating many other scenarios, as well as for planning VE operation and for managing the allocation of its resources to orders.

A SIMULATION SCENARIO

As a first step towards building a scenario for simulation we postulate that a VE is a network of interconnected autonomous units, each unit being an organisation or individual. Links between the units may be autonomously and dynamically established, dropped and re-established depending on the VE needs (self-organisation). There is a considerable uncertainty as to capacities required for non-core activities and therefore each VE tends to have a partnering arrangement in place with a larger number of companies or individuals than absolutely necessary (redundancy), just in case that some of them will be busy when the services are needed. Since all semi-permanent partners operate in the same highly volatile environment, it is in their own interest to be interconnected with many potential purchasers of their services. As competitive conditions change over time, VEs may permanently drop connections with some of the old constituent units and seek to establish links with new units (evolution). VEs typically co-exist and compete/collaborate with other VEs and since they all try to improve their performances in respect to each other concurrently (co-evolution), they create an ever-changing environment. Not every VE gets its game right - there are always companies which under perform and those that disappear. New companies are formed and they join the market and compete for the requisite number of connections. Global Economy performs as the natural ecology.

GLOBAL MARKET AS A COMPLEX ADAPTIVE SYSTEM

There is ample evidence that as the number of organisations connected into Global Economy increases, markets begin to behave as Complex Adaptive Systems (Holland, 1988). Complex Adaptive Systems are characterised by high dynamics and uncertainty. It is said that they operate at “the edge of chaos”, the expression that denotes a state of permanent change. Uncertainty must be sufficient to enable a free flow of information but certain stability (predictability) must be present to enable formation of messages. The processes of evolution and co-evolution in these systems are irreversible (Kauffman, 1995).

The complexity is a result of an exceedingly large number of participants pursuing own objectives and in the process initiating events that are unpredictable to other participants. National economies, traffic in a large city, ecosystems and large markets are typical examples. However, the authors have found that virtual enterprises, when considered at the level of individual resources, including elements of organisational knowledge, working capital, human resources, machines, work in progress, computers and buildings, behave as complex adaptive systems. If this assumption is true, the key issue in designing a VE is to determine a correct amount of uncertainty, which needs to be built into its organisational structure to maintain the system at the edge of chaos and prevent it to relapse into equilibrium or descent into chaos. An answer to this question can be obtained by modelling complex systems in terms of Intelligent Agents interacting in groups according to local rules and generating Emergent Behaviour (Holland, 1998a).

A NEW VE SIMULATION MODEL

The key elements of the model are Intelligent Agents, which are computer programs with certain advanced characteristics. For example, intelligent agents can communicate with each other, as well as with users, and can interpret meanings of messages. Agents collaborate and compete with each other, depending on the particular situation, but, in any case, they always work as a team. All the rules, according to which agents work, are specified in the so-called Ontology, which represents the repository of concepts of the domain under consideration. The important feature of our Ontology is that it can be modified by simulator users without any knowledge of programming using a user-friendly ontology editor.

To simulate the operation of a networked VE we assign an agent to each resource in the organisation, as well as in all partner organisations connected into the organisational network, and also to every enquiry or order arriving from customers. Through the process of negotiation among agents representing the demands (enquiries/orders) and those representing resources (skills, machines, capital, etc.), a schedule for deployment of resources is derived for every inquiry and each order. The negotiation between agents is conducted within the Virtual World, which is a model of the VE that is being investigated. The software is designed to accommodate hundreds of thousands of agents working in parallel and is therefore capable of simulating sizable networks and exhibiting emergent properties. The process of agent negotiation is driven by an Engine, which is generic and capable of supporting a wide variety of simulators and schedulers.

Given a known distribution of orders and enquiries the system can be used for determining types and quantities of resources required to meet the projected demand. It can be used thus to establish the number of constituent units of a VE that offer a sensible redundancy as a protection from a low-capacity risk. The dynamics of connecting, disconnecting and re-connecting constituent units (selforganisation) can be simulated, as well as the process of abandoning some of the old units and linking with new resources (evolution).

Most of the simulator code is written in C++ and the multi-agent system runs on a single or a network of Window XP Professional platforms. Ontology of a section of VE is shown below in the form of a semantic network with objects, attributes, scripts and links.

WHY AGENT-BASED MODELLING?

Agent technology provides possibilities not available in conventional simulators (Casti, 1997). The concept of the Virtual World (Rzevski, 2002), which is a constituent component of our multi-agent systems, provides a model of a VE resources (human skills, servers, methodologies) and demands for resources (orders, projects, tasks, enquiries) to a great detail (Batishchev et al, 2001). One workstation can cover up to 400,000 resources/demands. If a larger number is required a network of workstations can expand this number by an order of 10 or 100. Agents are capable of simulating autonomous behaviour of each networked unit in terms of co-operation strategies, policies on redundancy (risk management), special offers and capacity limitations. Above all, a multi-agent simulator represents a virtual society of pro-active and intelligent participants reflecting situations in real-life VEs (Rzevski et al, 2001).

In highly dynamic business situations simulators based on distributed decision making mechanisms, such as our multi-agent simulators, offer a distinct advantage because of the capability to renegotiate previously agreed decisions and thus accommodate unpredictable changes in demand and supply.

Therefore, the effectiveness of a multi-agent simulator is to a considerable extend determined by agent negotiation strategies. These strategies are in turn specified by negotiation protocols, which define rules for constructing and dispatching of messages and are stored in ontology. Let us consider an example of protocols for negotiation between a Project Agent (Demand Agent) AP and a Programmer Agent (Resource Agent) AE. The agent AP begins the negotiation process by enquiring about programmer's skills. If the answer is satisfactory, the agent AP enquires about programmer's experience. Assuming that the answer is again satisfactory, negotiations turn to the deadlines and available capacities. The agent AE may find it necessary to interrupt the negotiations with AP in order to negotiate a delay in delivering another less important task and with that negotiation completed to return to further discussions with AP. A more complex protocol for negotiations between a demand agent and a resource agent is shown below.

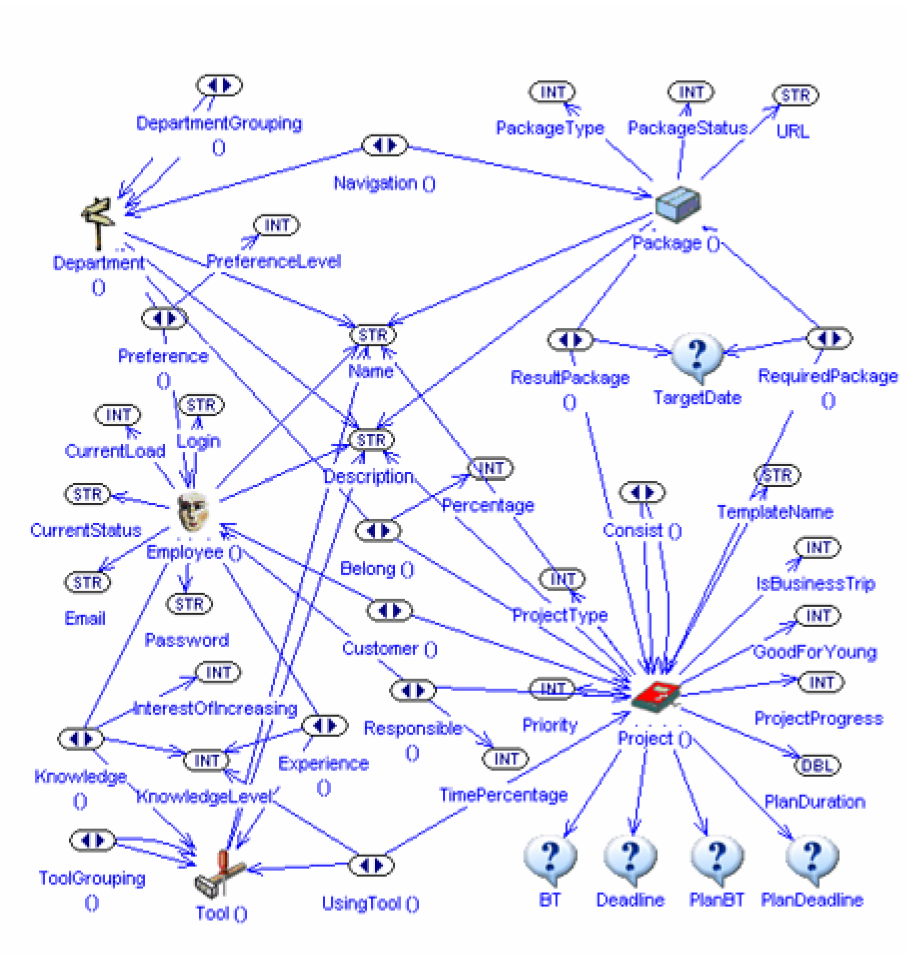

Fig1. An ontological model of a section of a VE

Magenta Simulator incorporates in its intelligent virtual network a special type of agents, which look after skills of VE employees. Their task is to monitor and improve the employability of theirs client by keeping records of their rejections due to inadequate skills or experience when they apply to participate in projects and to propose and schedule suitable training. Skills Agents are capable of negotiating training places for clients in internal or external training establishments and recommending distance learning courses.

To increase flexibility of multi-agent VE simulators, an editor has been developed which enables the domain knowledge as well as negotiation protocols to be modified from websites, usually located on company intranets. Simulator users without any programming knowledge may adjust elements of ontology to suite their particular requirements without any involvement of simulator designers.

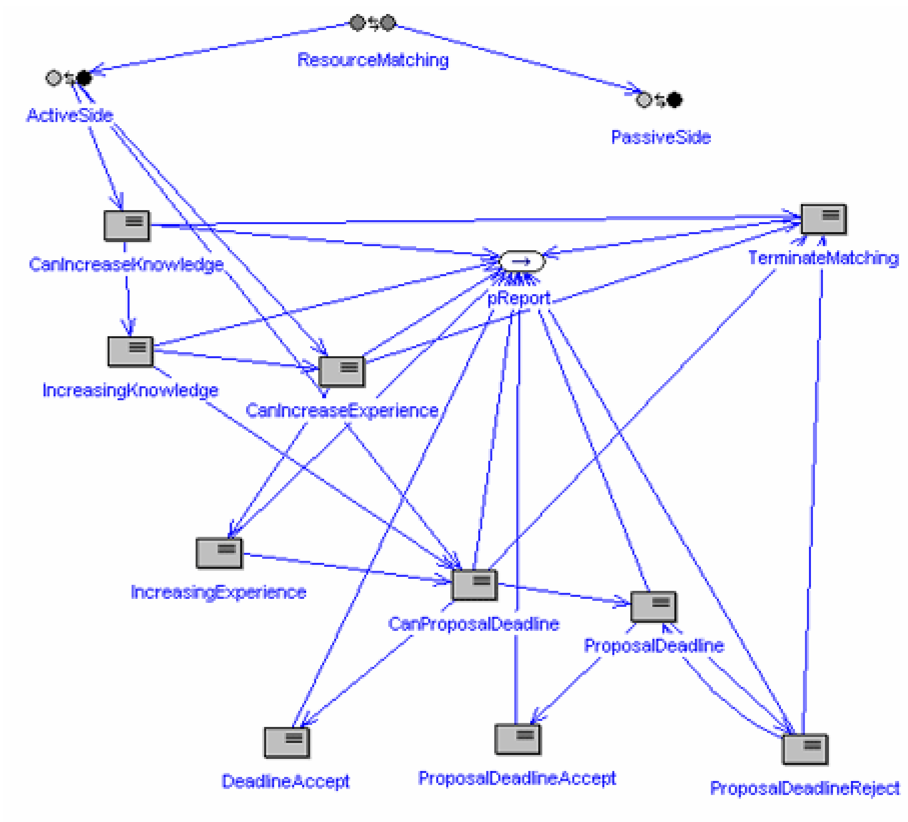

Fig.2 A negotiation protocol for demand and resource agents discussing how to deliver a task.

CONCLUSIONS

The hypothesis of this paper is that distributed intelligence multi-agent systems are far more effective simulators of virtual organisations than conventional centralised software products. There are two key features of distributed intelligence which support the hypothesis.

The first is the separation of the specific domain knowledge on VE from generic algorithms for managing communication between intelligent nodes and representation of this knowledge in terms of objects, attributes, scripts and links in ontology. This particular structure of ontology enables models of VE to be built in terms of free markets in which there is incessant negotiation between (1) internal VE resources and (2) external demands for these resources.

The second feature is group decision making by interaction between intelligent agents negotiating on behalf of demands and resources. This enables each stakeholder in a VE to be represented in the negotiation process and enables the system to rapidly react to changes in supply and demand by re-negotiating previously agreed arrangements.

Tools for building ontological VE models and an engine for running a very large number of software agents have been developed and tested by authors. The developed ontology-engine system is generic and can be used for simulating a wide variety of complex adaptive systems. For example, it has been recently successfully used for modelling of large fleets of tankers and very large supply chains, which are subjects of other publications. As far as modelling of large VE is concerned, the proposed approach is yet to be fully evaluated. The authors have built a VE ontology and run simulations of moderately large virtual organisations. The system is offered here as a promising framework rather than a proven method.

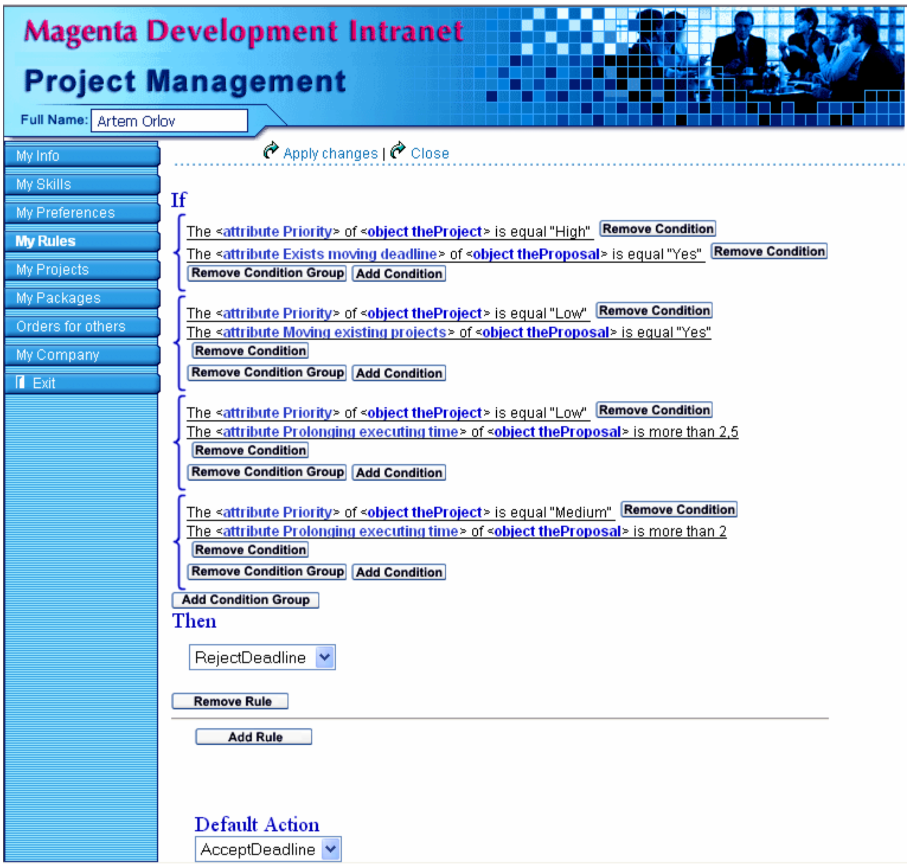

Fig 3. A rule editor, which can be used by simulator users to alter elements of ontology from websites

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