EVOLVING AGENT COMMUNITIES FOR INTELLIGENT INFORMATION PROCESSING IN WEB-BASED ENTERPRISE-WIDE INFORMATION SYSTEMS

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Abstract. The paper presents the approach to modelling virtual/real enterprises based upon the metaphor of a dynamic task oriented intelligent software agent community[1]. A virtual/real enterprise is modelled by the collection of evolving Multi-Agent Systems (MAS) representing the departments. The departments communicate with each other via the Proxy Agents representing their heads and those executives who are in charge with some external communications/functions. These Proxies in turn form the Enterprise MAS on the higher level. On the lower level each member agent of the department MAS may be expanded into the sub-ordinate MAS having the same Generic Architecture. As far as these department models represent enterprise functional nodes they are predesignated to perform business processes - i.e. tasks. These tasks performed by information systems are merely the tasks of information acquisition, integration, mediation and interchange. MAS members with various specialisations dynamically form communities to execute these tasks. Enterprise-wide information system operates on the Intranet in case we deal with modelling of a real enterprise and on the Internet otherwise. Users perceive this information system as Virtual Information Space with native Unified Virtual Interfaces.

1. INTRODUCTION

Researches today pay keen attention to the problems and the methods of virtual (as well as real) enterprise modelling. Growing interest to this domain may be explained by the expansion of distribution and virtualisation in manufacturing commerce, academia (rapid growth of diverse "hows" for doing real business by virtual means - electronic commerce, for instance - is a good example) as well as by the necessity to supply existing models and legacy systems with some dynamic character. It can be easily seen that the problem posed like this reflects the point of view of external observer or counter-agent interacting with virtual/real enterprise from outside. Another problem of similar importance is to create comfortable environment for the individuals acting inside the dynamic system - i.e. persons in charge of some certain functions and participating in business processes. This internal point of view has, as its main goal, the task of bridging diverse semantic gaps between native-to-user ways of presenting information and posing problems, from one side, and the elements of information systems (IS) with formalised action interfaces from the other side of the ferry.

In the domain under examination the paradigm of virtual information space (VIS) is likely to be an acceptable way to model virtual and/or real enterprise. It provides suitable methods to represent these complex dynamic systems by means of terms of integrated Information System (IS) composed of distributed component ISs, operating heterogeneous information resources as it was reported in [1].

It is evident that the problem of modelling of a virtual or a real enterprise by means of an integrated IS as sketched before is twofold. From one hand it is the problem of bridging semantic, operational and psychological gaps between the human actors and their artificial IT counterparts. From the other side it is the problem of semantic interoperability among the participating heterogeneous distributed components - i.e. operationally - mediation, communication and co-ordination among these parties. The problem becomes even more complicated if the aspect of evolution of the participating actors (as well as the underlying information resources described with various data models) is taken into consideration.

The paper presents the approach to obtain the solution based upon the metaphor of a dynamic task oriented intelligent software agent community. A virtual/real enterprise is modelled by the collection of evolving Multi-Agent Systems (MAS) representing the departments. The departments communicate with each other via the Proxy Agents representing their heads and those executives who are in charge with some external communications/functions. Those Proxies in turn form the Enterprise MAS on the higher level. On the lower level each member agent of the department MAS may be expanded into the sub-ordinate MAS having the same

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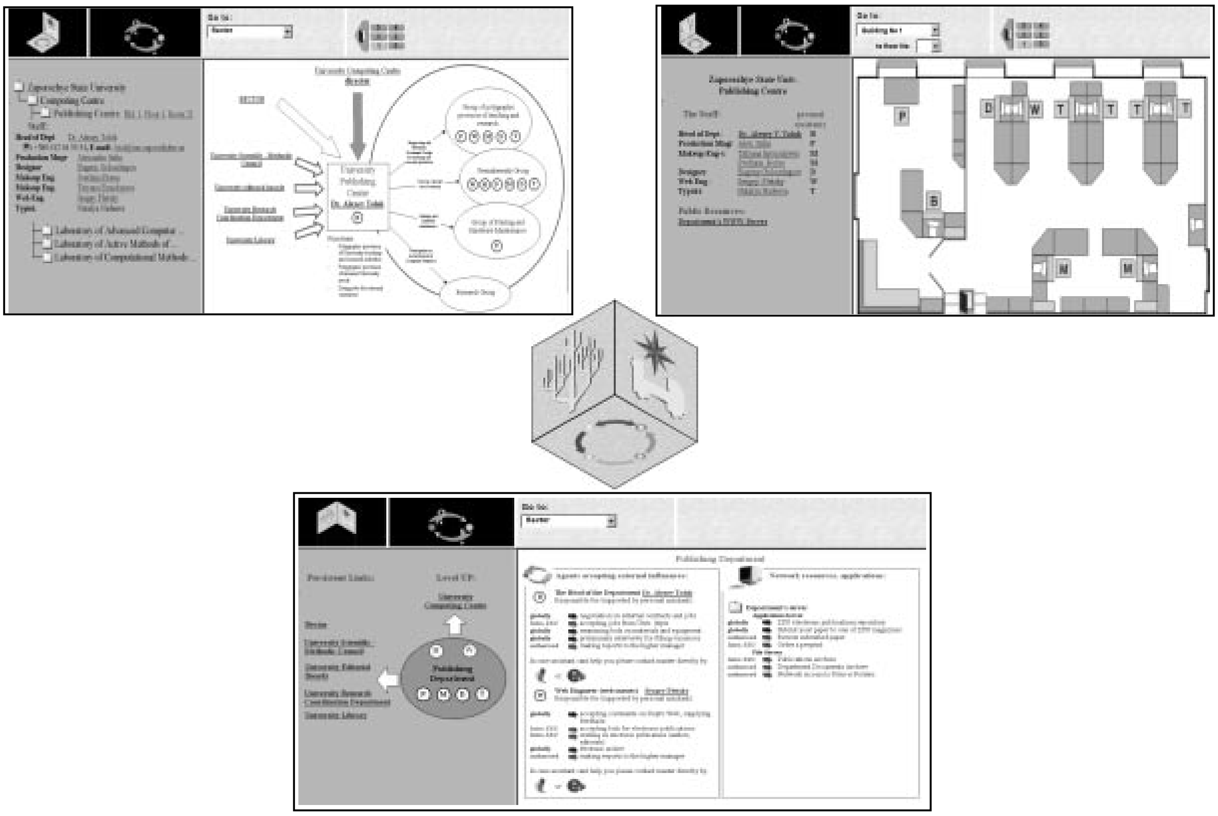

Fig. 1. VIS Hypercube gateways for ZSU Publishing Department

Generic Architecture. As far as these department models represent enterprise functional nodes they are predesignated to perform business processes - i.e. tasks. These tasks performed by information systems are merely the tasks of information acquisition, integration, mediation and interchange. MAS members with various specialisations dynamically form communities to execute tasks. The staff operates on the enterprise Intranet in case we deal with modelling of a real enterprise and on the Internet otherwise. Users percept this enterprise-wide information system as Virtual Information Space [2] with native Interfaces. The approach presented exploits the Diakoptical MAS framework [3], the model of task execution by the Agents Community [4]. User interfaces are based upon the concept of the Unified Virtual Intranet Interface (UVII) [5,6].

The paper is structured as follows: Section 2 sketches the VIS with its faces; Section 3 is presents VIS functional face as the framework for business process modelling; the contribution of Section 4 is the discussion of the aspects of agents' and underlying information resources' evolution; Section 5 summarises the results and outlines the prospects for further research.

2. ENTERPRISE MODELLING: WEB BASED VIRTUAL INFORMATION SPACE

The solution of the interface part of the problem of modelling of virtual/real enterprise is seen on the way of designing VIS [2,5,6] as the logical build-up over the underlying collection of distributed information systems. VIS and its correlation to the common notion of an interface is denoted as follows:

VIS is VIRTUAL due to the fact it comprises diverse distributed software components: legacy IS-s, data and knowledge bases, clients, servers, various types of agents and agent societies and presents them uniformly, by means of Unified Visual Intranet Interface (UVII).

VIS is an INFORMATION system because its major function is information acquisition, integration, mediation and interchange and because it is built upon a multilevel enterprise IS architecture [2]. The access to Enterprise IS is facilitated by UVII. UVII, in turn, defines the rules and the procedures for human to VIS, human to agent, agent to agent interaction on different levels of enterprise model as well as on different layers of underlying IS architecture.

VIS is a SPACE because it has some spatial properties. Topological, structural and functional projections are assumed to be the three basic faces of VIS hyper-cube (see Fig. 1). VIS interface context should therefore clearly define not only the appearance, the navigation and the functionality for each of the faces, but also the interrelationships between these projections - the gateways from one face to another - i. e. the inter-faces.

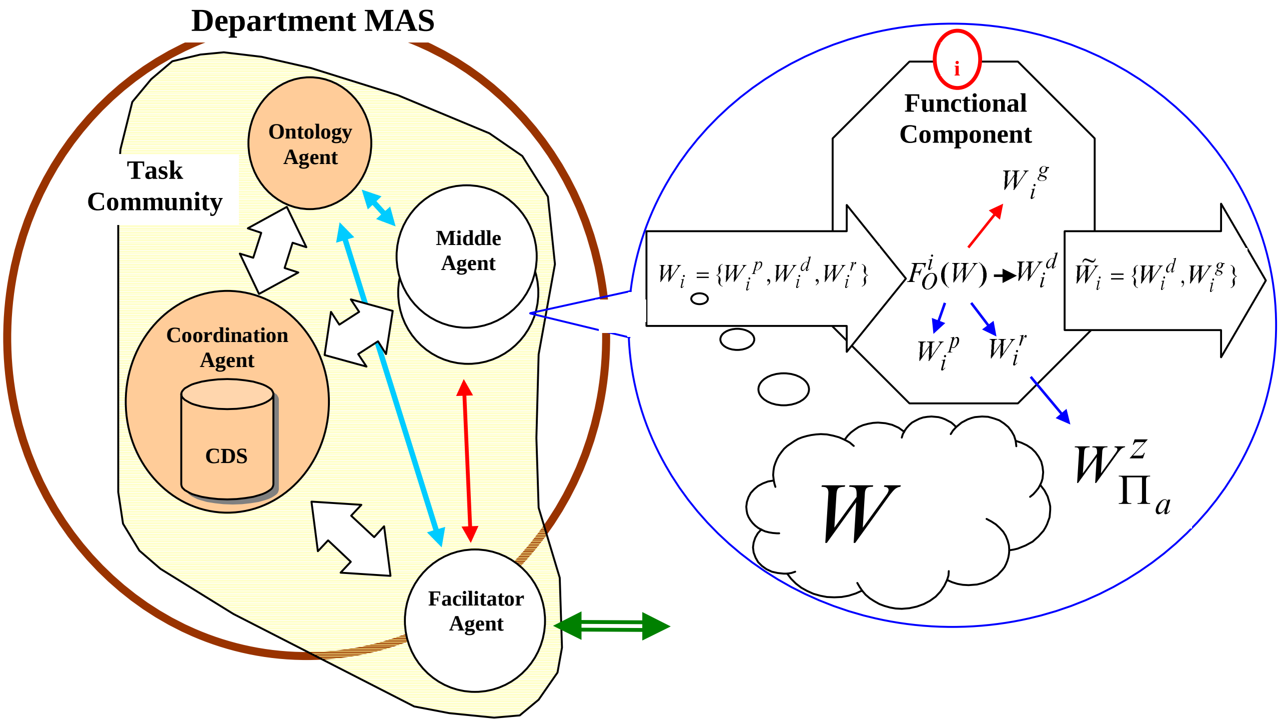

Fig. 2. Functional system/component model.

While modelling an enterprise real world elements and relationships from several points of view are examined. The first viewpoint is topological and it should answer the questions like:

How do the building and floor plans look like?

What is placed to the room N on a certain floor plan?

What are the network nodes presented by the plan of room N?

What are the shared resources of workstation S?...

Whereas the second point of view is structural or organisational and is aimed to resolve the following problems:

Where is department D: buildings, floors, rooms?

Who is the head of department D and what does his/her staff comprise?

What is the structure of department D and the relationships to another departments?...

And one more point of view is functional. The tasks to be solved in frame of this projection are as follows:

What are the services and information resources provided by room N, department D or server S?

Which enterprise elements will supply us with the answer to the request/query R?

What information we may and what information we may not expect to receive?...

In frame of UVII interface objects are classified by belonging to a certain modelling scope: topological, organisational or functional. The Generic Architecture of the agents comprising enterprise and department MAS exploits UVII as the interface to the human user (agent's master).

3. FUNCTIONAL FACE: FRAMEWORK FOR BUSINESS PROCESS MODELLING

As it was outlined before VIS Functional Face is inhabited by Multi-Agent Systems representing enterprise structural elements on various levels. The member agents dynamically form task oriented communities for the execution of the tasks of information acquisition, integration, mediation and interchange emerging within MAS of one or another level.

In real life these tasks are decomposed and executed by groups of functional components. Traditional models of the processes of information interchange are often based on the usage of structured collections of rigid relationships among the participating functional nodes. When modelled within the majority of MAS, the tasks are represented by plans - pre-defined oriented graphs, Petri Nets, etc. These representations are often too much static and do not fully cover the things humans meet in real life. If we take decision making process for an instance, it can not always be adequately modelled by, say, a hierarchy of rigidly positioned actors. Humans apply much more soft interrelationships to solve the problem: brainstorming, informal discussion, whatever.

Another big pitfall traditional representations suffer from is that rigid relationship models are not really scaleable.

The main difference of the applied task execution model [4] is the absence of these rigidly pre-defined task specifications. The tasks within VIS Functional Face are "summoned" by its Proxy and Facilitator agents and are executed by its middle agents. Middle agents dynamically form communities to perform emerging tasks. An agent joins the community if and only if it accepts a sensory input containing the (sub)set of atomic works (being the part of the task) for the execution. The task execution plan is thus being developed in more and more details within step-by-step task execution process. The process is conducted by the task community member agents. Community member agents act as the models of the functional components of the corresponding real world entity (see Fig.2). A case study of planning process modelling by simulation in frame of the discussed approach is given in [7].

4. THE EVOLUTION OF ENTERPRISE MODEL COMPONENTS

One of the major characteristics of a virtual/real enterprise is its inclination to changes. The framework for enterprise modelling should therefore possess the means to deal with the changes emerging within the real world - i.e. the models applied must cope with various types of evolution. Enterprise modelling framework under discussion distinguishes and handles the movement in:

- Agents' state constraints - the *capabilities* to execute a work
- Agents' conceptualisations (*beliefs*) about their partners - task community members
- *Information resources* and corresponding *metadata*

Capabilities' evolution according to [3] is understood as the process of agent (say, A) transitions from one state s_i to another state s_j. A as an autonomous entity performs these transitions according to its own decisions taken in frame of one or another atomic work (policy) execution. Consequently, the "manner" agent A executes policy f, as well as the constraints on policy incoming parameters X_f depend upon the state of agent A. Thus, evolution of an agent is the evolution of its role. The set of states of agent A is defined as follows:

The set of states of agent *A*: $S_A = \{s_1,...,s_n\}$ - is the set of 3-nested tuples $s_i, i = 1,...,n$:

$$s_i = \{r(X_A), q(F_A), t(F)\}, \tag{1}$$

where:

$r(X_A)$ - the set of constraints over the system parameters X_A of agent A, applied in state s_i (parameter constraints),

$q(F_A)$ - the set of constraints over the set of authorised policies of agent A in state s_i (parameter constraints),

$t(F)$ - the function denoting transitions from state s_i to another permissible states from S_A resulting from the execution of the policies $F = \{f_1,..., f_j,..., f_m\}$ of agent A.

Beliefs' evolution is closely tightened to the monitoring of task community members' capabilities to perform works. According to [4,7] inter-agent communication and work execution is organised via parametric feedbacks, comprising the information on the current capabilities to execute the certain work. The capability returned by the executor *A* to the requestor *B* is, thus, the function from work (policy) parameters $c_A^f = c(X_f)$, $c_A^f \in [0,1]$. An agent (representing the model of a real world functional component) monitors the capabilities of its counter-agents for to intelligently assign works to the executors with probably better capabilities in future tasks. The beliefs on counter-agents' probable capabilities are maintained in the form of matrix

$$\mathbf{C} = \begin{array}{c} \\ A_1 \\ \cdots \\ A_i \\ \cdots \\ A_n \end{array} \begin{array}{c} \begin{array}{ccccc} w_1 & \cdots & w_j & \cdots & w_m \end{array} \\ \begin{bmatrix} c_1^1 & & c_1^j & & c_1^m \\ & & \cdots & & \\ & \cdots & c_i^j = c_{A_i}^{w_j}(X_{w_j}) & \cdots & \\ & & \cdots & & \\ c_n^1 & & c_n^j & & c_n^m \end{bmatrix} \end{array}, \tag{2}$$

where dimensions *n* and *m* grow in the process of evolution reflecting the income of new knowledge on counter-agents (*n*) and the works they are probably capable to perform (*m*) to matrix **C**. The upper bound for dimension *n* is the number of member-agents in the MAS comprising the holder of matrix **C**. The maximum value for *m* is the cardinality of the set *W* of permissible works [4] for the mentioned MAS.

Information resources and metadata changes are maintained locally by corresponding information systems - resource providers. Within VIS information resource providers are represented by their wrapper agents. Wrapper agents are the members of appropriate department MAS. Several approaches to cope with information resource evolution are under investigation. One of them is based on the application of Active Data Dictionary approach [8] and the extension of the Relational Data Model with Control Attributes to handle program code - (meta)data consistency. The approach to cope with interoperability upon heterogeneous data with disparate data models is based on the application of canonical metadata representations [9].

5. SUMMARY AND FUTURE WORK

The paper presents the framework for the design of the enterprise-wide integrated intelligent information systems modelling business processes for real as well as virtual enterprises. The approach to the design of such intelligent systems, comprising distributed heterogeneous intelligent components on various levels, is based upon the paradigms of intellectual software agent, multi-agent system, evolving task-oriented agent community. Virtual Information Space with its Unified Virtual Intranet Interface is proposed as the unifying architecture for the design of the enterprise-wide integrated intelligent information systems. The particularity of the paper is provided by the presentation of the model coping with the evolution of the agents representing enterprise/department functional components. The evolution model presented distinguishes the aspects of agents' capability, belief and information resource movement. The plans for further research and development are as follows:

The development of the architectural framework. The layered architectural framework utilising the theoretical models of [1-4] is under development and will soon be deployed. The layers of the agents community architecture will comprise: generic agent architecture, agent-to-agent interface specification, communicative acts specification, task-oriented agents community specification comprising agents specialisation and feedback co-ordination method, ontology representation, knowledge sharing and interoperability issues.

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