Information Fields in Organization Modeling using an EDA Multi-Agent Architecture

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Abstract

The EDA model (Epistemic-Deontic-Axiological) is an agent model based on the social psychology theoretical classification of norms and corresponding attitudes: Ontological, Epistemic, Deontic and Axiological. EDA agents are situated in normative information fields, and are described in terms of the basic attitudes aforementioned. Information fields are used as the basis for coordinating an organization, which is seen here as a collective agent composed of other individual and/or collective agents and/or roles, that encompasses multiple embedded information fields. The paper discusses coordination and the representation of social structures based on using the EDA agent model combined with the notion of information field.

Introduction

The norm-based framework that we propose here assumes that organizations can be modeled as abstract specifications, irrespective of the actual agents that will populate them, which in many cases can be both human and artificial. We believe that some of the many roles human agents perform in an organization – namely the less creative, less prone to exceptions and more repetitive ones – can be partially delegated to artificial agents, although we consider that keeping the ultimate responsibility in the human agent is unavoidable.

The essential units in our model are the organizational roles and their relationships. The EDA model, described in this paper, was mainly conceived to facilitate the creation of social environments in terms of normative intelligent multi-agent systems (Filipe, 2000). The focus of our approach differs from other multi-agent systems approaches (Cohen and Levesque, 1990; Rao and Georgeff, 1991; Jennings, 1994), which mainly focus on the design of the internal (mental) structures of single agents instead of the normative (social) shared structures that underlie multi-agent co-operation.

Here, we seek to describe how to build an organizational model based on the multi-agent system metaphor using the EDA agent model for providing a full life-cycle method that guides the designer in the model development all the way from the conceptual level to implementational level. In that process we adopt an organizational semiotics perspective (Stamper, 1973).

Semiotics and Business Process Modeling

Semiotics is the science of signs (Peirce, 1931-58). Signs are social constructs that require meaning assignment. The semiotic approach to computing in organizations (Stamper, 1973, 2000), adopts a constructivist perspective and emphasizes the importance of the integration of computers in social reality. It is very important to make computer-based systems fit into a business organization and integrate information technology with the social aspects that enable the successful fulfillment of business goals. Sometimes highly sophisticated technology is applied without a clear understanding of the information circuits and information systems already in place.

Norms are social constructs that represent business rules, social goals, constraints and other structural aspects of the organization and are essential for defining an agent's roles, including the specification of its functions and obligations. The adopted approach views a business process as a process-oriented network of autonomous normative agents. Agents can represent individuals or collectives, including external stakeholders such as customers, regulators or suppliers, and internal entities such as staff, departments, or systems.

The EDA Model

Using the social psychology taxonomy of norms, and based on the assumption that organizational agents' behavior is determined by the evaluation of deontic norms given the agent epistemic state, with axiological norms for solving eventual conflicts of interest, we propose an intentional agent model, composed of three main components: the epistemic, the deontic and the axiological.

- Beliefs are incorporated in the *Epistemic* component,
- Obligations, rights and behaviors are incorporated in the *Deontic* component, and
- Values (using a partial order relation of importance) are incorporated in the *Axiological* component.

Figure 1 depicts the EDA model and its component relationships.

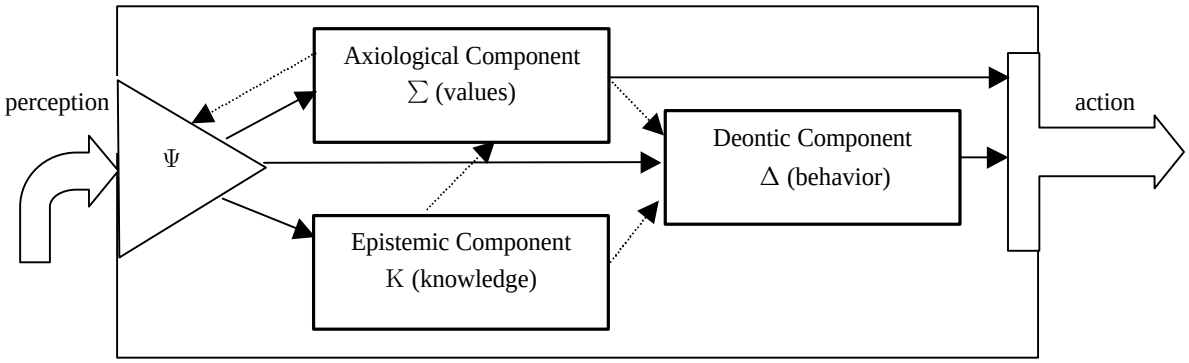

Figure 1: The EDA model component relationships.

Ψ is a pragmatic function that filters perceptions, according to the agent ontology, using perceptual and axiological norms, and updates one or more model components.

∑ is an axiological function that is used mainly in two circumstances: to help decide which signs to perceive, and to help decide which goals to put in the agenda and execute.

K is a knowledge-based component, where the agent stores its beliefs both explicitly and implicitly, in the form of potential deductions based on logical reasoning.

Δ is a set of plans, either explicit or implicit, the agent is interested in and may choose to execute.

The detailed description of each component, including its internal structure, is provided in (Filipe, 2000).

Issues Involved in Building Normative Multi-Agent Systems

The EDA model is a normative intentional model developed for facilitating the analysis and design of coordinated behavior in organizations. More specifically, we propose the use of the EDA model in collaborative[1] multi-agent environments.

Since, according to our definition of an agent, agents must choose in a rational, autonomous and pro-active way their next actions (Wooldridge and Jennings, 1995), all agents are assumed to be rational decision systems, although the utility they tend to maximize may not necessarily be of an economic nature.

The collaborative behavior requirement places several practical constraints on the multi-agent structure:

- Agents need to have an information discovery mechanism through which they discover the existence, the location, and the roles of other agents, especially their capabilities, controlled resources and power relationships. This can be done using a special agent with whom other agents register. Such an agent acts simultaneously as a namespace server and a yellow-pages agent and will be referred hereafter as a facilitator.
- Agents need a standard communication environment, including a standard language that establishes a communication channel through which agents are able to transmit and understand (syntactically) their messages.
- Agents require an internal inference machine, that permits them to reason and make their choices, based on their EDA model state in each moment.
- Agents need to have a common conceptual framework, with a shared representation and understanding (semantics) of the common domain concepts. We assume agents use a shared ontology socially constructed (offline) using well-known methods of semantic analysis from organizational semiotics (Liu, 2000).

We are particularly interested in organization modeling; therefore in the remaining of this paper we will consider the application of the EDA model to organizations. We also postulate that organizations are structured in terms of roles and agents who perform those roles (Biddle, 1979).

Organizational Multi-Agent Architecture

Roles are structured descriptions of agent behaviors. A role includes the specification of what an agent is able to do, is authorized to do and is obliged to do. In this paper we sometimes refer to roles as abstract agents, *i.e.* as agent shells, that to become active require instantiation by an active entity (either human or artificial) that can actually

[1] We are however aware that collaboration and competition are two faces of the same coin (Holt, 2000), which cannot exist one without the other: the main reason for collaboration is the existence of scarce resources that need to be shared; however, that scarcity is also the seed of competition.

play the role. A role is thus necessarily defined prior to the assignment of an agent to fulfill it.

Figure 2 depicts the assignment of a role to an agent as an EDA model composition process. The composition process that operates in each model component is essentially the merge of the two sets of norms: the set that existed in agent with the set that is provided in the role.

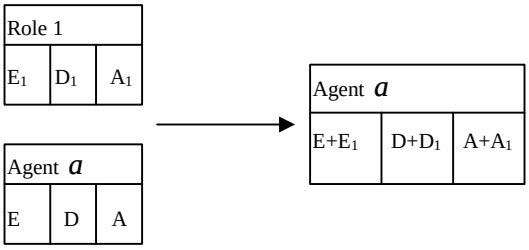

Figure 2: Role Instantiation / EDA Model Composition

Potential conflicts between the existing and the new EDA model components are avoided by keeping each knowledge statement indexed to the corresponding role. This indexing means that an agent may behave differently in different roles thus, inter-agent relationships such as conversations must always specify, either explicitly or normatively (by default), the roles in which each agent is participating.

A Role-Based Organizational Model

The role-based organizational model we propose originates the kind of structure depicted in figure 3.

This figure suggests that organizations are composed by roles and that roles are played by agents. There are three types in this diagram: one is the *organization*, another is the *role* and a third one is the *agent*. However, the relationships between them are not trivial. For example, in the figure we have depicted an organization instantiating a role; we have also tried to suggest that an agent can instantiate several roles, yet the following question may arise: "Can a role be played by more than one agent, simultaneously?" In role theory this is an open issue. However, due to the impact of the answer in design and implementation issues, we had to analyze the problem and make a decision. Before indicating our decision in this matter, we need to clarify what we mean by *conceptual role hierarchy*.

Conceptual Role Hierarchies

The most salient feature here is that roles in *conceptual role hierarchies* are defined in terms of specialization relationships of the type class-subclass or class-instance, (simply denoted as "is-a" relationships). This kind of role hierarchy is independent of the power relationships that also relate different roles in an organization. Conceptual relationships are useful for modeling different abstraction levels and decomposing the different roles in such a way that they can automatically inherit the properties from more general roles instead of repeating the same properties in many roles. Inheritance also provides an efficient way of ensuring consistency whenever a general property is changed and all subsumed roles must be changed accordingly. Figure 4 shows a simple example.

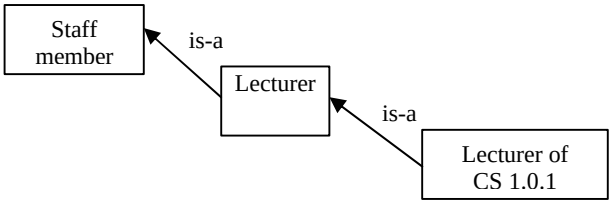

Figure 4: Conceptual role hierarchy

We could easily extend this example to add more roles under "Lecturer": one for each different course lectured at the Teaching Institution being modeled. If the CS 1.0.1 course had more than one lecturer (*e.g.* one for theory and another one for laboratories) then we would add two sub-roles to the "Lecturer of CS 1.0.1" role, denoted perhaps

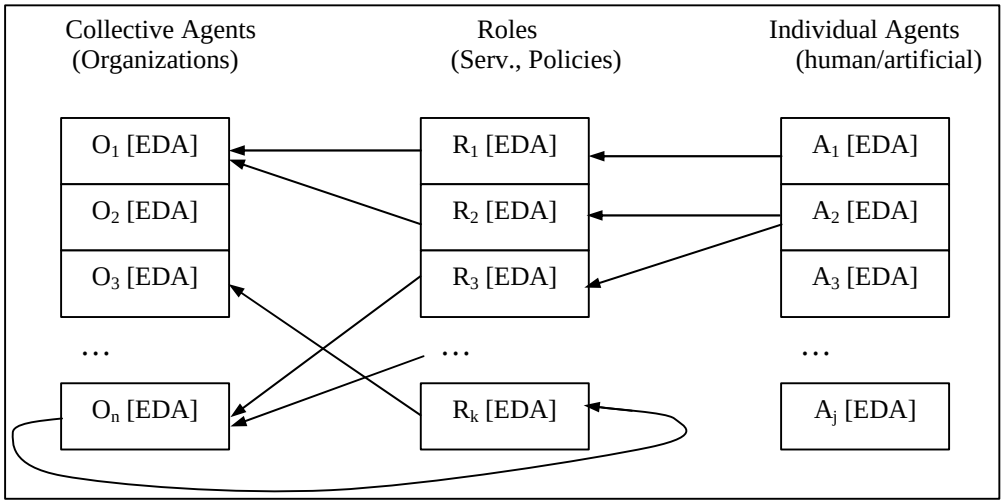

Figure 3: Organization-Role-Agent Architecture (3 classes)

by “Lecturer of CS 1.0.1 theory” and “Lecturer of CS 1.0.1 labs”.

Finally, we add a distinction that is relevant to the current discussion concerning the role-based organizational structure: we designate as “Role instances” all the roles that are “leaves” of the conceptual role hierarchy and we call “Role classes” the remaining ones. Furthermore, we postulate that our organizational model can only associate agents with role instances (not role classes). For example, although it makes sense to speak and reason about the concept of lecturer and its relationships with other organizational roles, it is not allowed to assign a particular agent to play the role of lecturer (e.g. the role of a lecturer of a particular subject, to a particular class might be adequate, admitting it would be a leaf in the role hierarchy).

Organizations, Roles and Agents

For the sake of simplicity, and without loss of generality or expressiveness, we postulate that a role can only be played by one agent at a time, although it can be an individual agent or a collective agent. Collective agents are co-ordinated entities, that have their own goals and their own knowledge, *i.e.* they are organizations. The instantiation of an organization is, however, different from the simple instantiation of a role, because in the case of an organization its instantiation requires filling in all its roles or at least a sufficient number of roles for enabling its functioning.

For example, the program committee of a conference is a collective agent, whose decisions concerning paper acceptance are taken using specific co-ordination methods, which plays a role in the conference organization. Another example: The scientific council of a School plays a role within the School organizational structure; it has a number of obligations and rights, and performs a number of legally instituted functions, which require the co-ordination of its members, typically using voting mechanisms. Each member of this collective agent performs a specialised role and the collective agent can be described as a composition of roles, which are instantiated by single agents. The examples illustrate the coherency between the collective agent concept, in our role-based multi-agent architecture model, and the concept of organization, as suggested above.

A relevant aspect of this architecture is that an organization belongs simultaneously to two classes: it belongs to the class of roles because it must be instantiated by (multiple) agents in order to become active and it belongs to the class of agents because it can instantiate a role in another multi-agent system; to enable this we assign an EDA model to every collective agent. In this way it becomes possible for an organization to maintain its knowledge even after a complete change of the agents that instantiate it, which would not be the case if all the knowledge would be kept at the individual agents’ EDA models. This important aspect is depicted in figure 5, indicating that organizations, roles and agents have different EDA models.

Assigning an EDA model to a role is required because the agent that instantiates it may change during the enactment of a business process and yet the process ought to continue without any interruption, as if the agent was the same. For example, if a customer places a complaint concerning a certain defective product to a company representative, and it calls back the next day to change a detail in its complaint, it is not relevant that it talks with the same or other representative – ideally the customer should be able to continue the conversation without knowing whether it is talking with the same representative or not.

Multi-tiered Organizational Layer

The highest normative layer is the organizational layer. However, since we postulate that any collective agent is an organization, the organizational layer may actually be composed by many organizational layers. Each layer corresponds to an information field since there is a one-to-one relationship between organizations and information fields.

Therefore, to be precise it is necessary to establish a priority order within this multi-tiered layer. By definition, an organization Org_1 subsumes another one Org_2 ($Org_1 \preccurlyeq Org_2$) if is situated at a higher layer. For example, the department of Informatics at the School of Technology of Setubal is a collective agent (organization) that is subsumed by the School of Technology of Setubal.

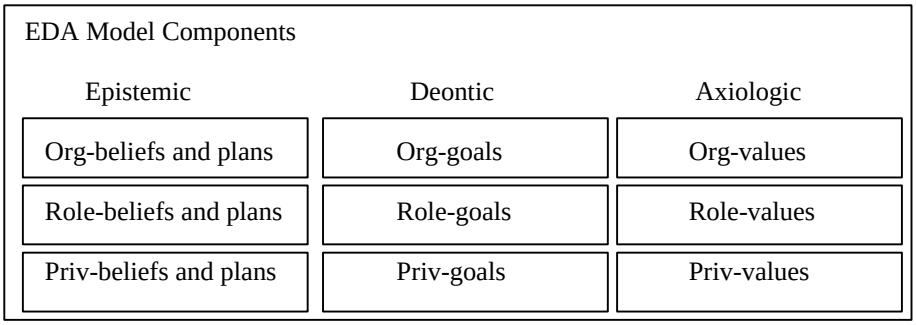

Figure 5: Normative knowledge levels

Therefore, it is possible that the department may have some specific beliefs, goals or values in addition to those prescribed at the School level. However, the department ought to be consistent with the norms defined by the School, otherwise a norm violation occurs.

We postulate – coherently with the principle of the *minimisation of conceptual distance*, proposed by Touretzky (1984) and also according to what is usual in human organizations – that in case of conflict between two organizational layers, the agents at lower levels ought to assign a higher priority to the hierarchically immediate organization.

Role Resolution and Role Relationships

Since we adopt the view that organizational co-ordination depends essentially on role interaction as much as the particular agent that instantiates it, organizational agent communication and co-ordination requires role resolution.

In our multi-agent system architecture we assign this task to the facilitator. The facilitator is also a domain name server where all the agents must register whenever they enter the network, indicating the role(s) they are playing. The facilitator has access to the organizational ontology and all role descriptions.

Whenever an agent requires an interaction with a certain role player it is necessary to identify the agent that is playing the role and ensure that the message is channeled to it. In some circumstances an agent who needs a particular service may request the facilitator to find out those agents that can provide the required service. This is a two-step process, involving firstly the identification of the list of roles that can provide the service and, secondly, the selection of one or more agents that play one of these roles, which the client is authorized to access.

A Collaborative Communicative Environment

In figure 6 we show the typical collaborative and communicative environment that we use for organization modeling and implementation. Below, we show how the EDA paradigm can be effective in the modeling of organizational multi-agent systems, bringing together several notions previously described.

The Pragmatics of the EDA Model

Conversations are meaningful sequences of speech acts that pragmatically modify the EDA models being used by both agents (sender and receiver). This is consistent with communication theories such as the Speech-Act Theory (Searle, 1969) or the Theory of Communicative Action (Habermas, 1984). However, it is not obvious whether the modification produced by a speech act is made at the agent level, at the role level or at the organization level.

Consider the following example: an agent A_1 is playing role R_1 in organization O_1, whereas agent A_2 is playing role R_2 in organization O_2; if A_1 needs to buy 100 screws from A_2, then where is this fact represented?

- It may be represented in the epistemic component of A_1, if no other agent will participate in the acquisition process;
- It may be represented in the epistemic component of R_1 if another agent, A_3, from the same organization O_1, can (e.g. in another shift) play the same role as A_1, and continue the transaction with A_2.
- It may be represented in the epistemic component of organization O_1, if handling this kind of requests can be performed by more than one role and there is a dynamic binding of requests to roles.

The procedure we propose for speech act pragmatic processing in organizational agents is the following: The speech act is always channeled first through the agent, so the decision procedure starts at that level: the agent must then decide, based on private and inherit deontic rules, whether the speech act should be processed at its private level and let it modify its private EDA model and/or it is of interest at a higher role level and, in that case, sending it up the nested EDA model hierarchy. Each role level would perform a similar decision process. The speech act upward movement can be blocked at any level, to avoid cluttering the higher levels, closer to central control.

In communicative action theory, Habermas (1984) postulates the existence of three worlds:

- The subjective world (how the speaker perceives the world) that is constituted by the feelings, beliefs, desires, experiences and intentions of the agent,
- The common social (inter-subjective) world that is constituted by norms, commitments, agent relationships, and institutions to which the agents belong themselves, and which defines how agents stand towards each other, and
- The objective world of objects and states of affairs (external world) that describes “how things are”.

The pragmatics of speech acts may impact any or several of these worlds, therefore we need to address this problem in terms of the EDA model application and the information space concept.

Since we are interested in using the organizational models for partially automating certain organizational tasks, we are interested mainly on aspects that can be formalized, because formalization is a precondition for automation. In organizational settings the subjective world seems to be too complex to be formalized and the objective worlds seem to be relatively easy to model using conventional methods, thus we will address here the social world (inter-subjective world).

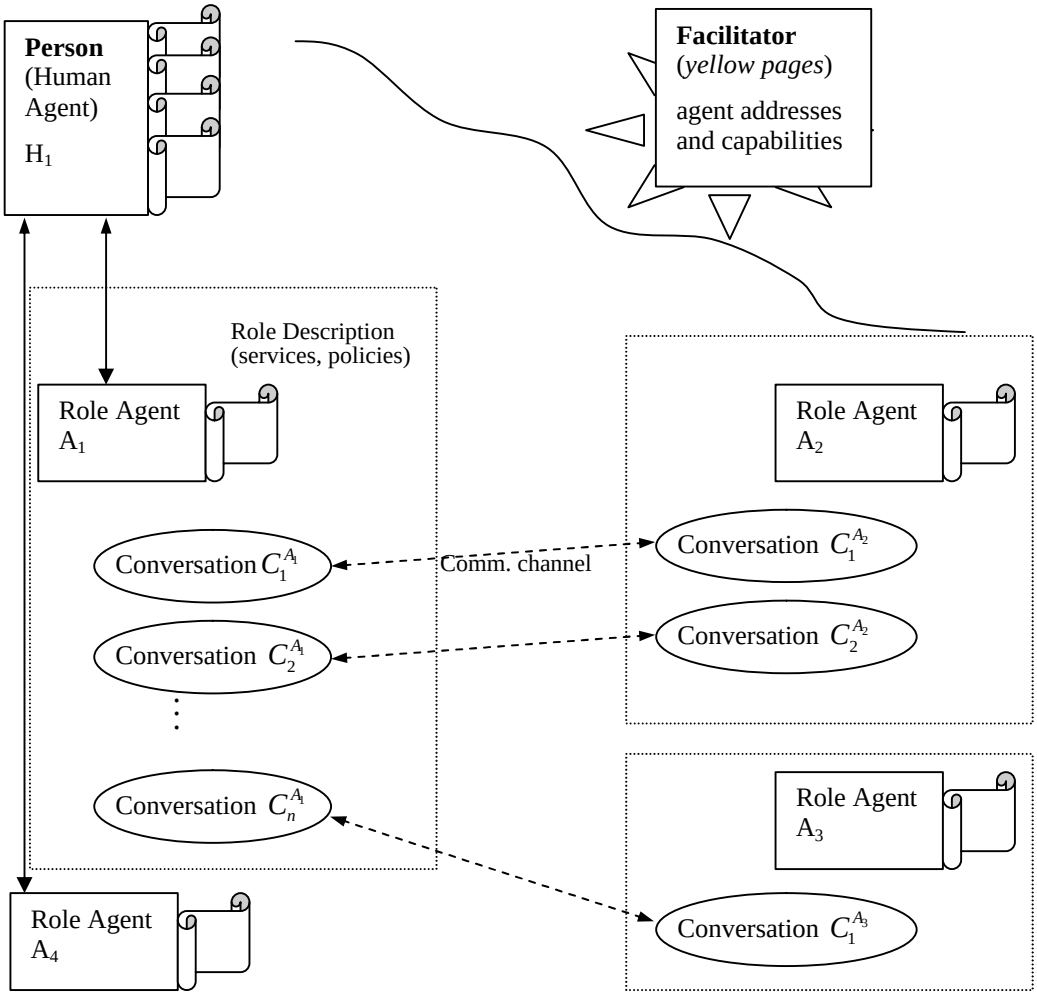

Figure 6: Collaborative Multi-Agent System Architecture

The Representation of Social Objects

In the inter-subjective world a shared ontology or inter-subjective reality that defines the social context (information field) where agents are situated. This kind of social shared knowledge is not reducible to individual mental objects (Conte and Castelfranchi, 1995). For example, in the case of a commitment violation, sanction enforcement is explicitly or tacitly supported by the social group to which the agents belong, otherwise the stronger agent would have no reason to accept the sanction. This demonstrates the inadequacy of the reductionist view.

Once again, we look at human organizational models for designing multi-agent systems: contracts in human societies are often written and publicly registered in order to ensure the existence of socially accepted, and trusted, witnesses that would enable the control of possible violations at a social level. Non-registered contracts and commitments are often dealt with at a bilateral level only and each concerned agent has its internal contract copy. This observation suggests two possible representational models:

- A *distributed* model: Every agent keeps track of social objects in which that agent is involved and may also be a witness of some social objects involving other agents.
- A *centralized* model: There is an Information Field Server (IFS) that has a social objects database, including shared beliefs, norms, agent roles, social commitments, and institutions.

The distributed model is more robust to failure, given the implicit redundancy. For example, a contract where a number of parties are involved is kept in all concerned agents' knowledge bases, therefore if an agent collapses the others can still provide copies of the contract. It is also more efficient assuming that all agents are honest and sincere; for example, commitment creation and termination involved in business transactions would not need to be officially recorded – a simple representation of a social

commitment at the concerned agents EDA model would suffice.

However, since these assumptions are often unrealistic, the distributed model cannot completely replace the role of certified agents, trusted by society to keep record of shared beliefs and social commitments. We assume here that these social notions are part of the ontology that is shared by all members of an information field; that's why we call these trusted repositories of the shared ontology "*Information Field Servers*". These servers have the following characteristics:

- Different information fields must have different IFS because the shared ontology may differ among specific information fields.
- Each information field may have several non-redundant IFS, each representing a small part of the shared ontology.
- The robustness problems of IFS are minimized by reliable backup (redundant) agents.

Communication bandwidth is another relevant factor to consider: if all social objects were placed in central IFS agents these agents might become system bottlenecks.

In figure 7 the architecture of the inter-subjective level is depicted with respect to the localisation of social objects in addition to showing an example of how social objects are used at the subjective level.

This figure emphasizes commitments. Commitments are actually very important coordination instruments. They consist of conditional obligations to do some action (*e.g.* contracts), thus they are represented in the deontic part of an EDA model. In the social EDA model we propose they are first class objects that can be represented either in the agents' EDA models (which we designate as the agents' space) or in the IFS' EDA model (which we designate as the Information Field Server's space). In the example above, agents A1 and A2 have only an internal representation (in each EDA model) of a shared commitment C1, whereas Agents A2 and A3 do not have an internal representation of commitment C2 because this commitment is represented in IFS_1. All agents A2 and A3 need is a reference (*i.e.* a pointer) to that shared commitment. The latter solution is preferred for commitments that the agents intend to make public, and in that way make the commitment stronger.

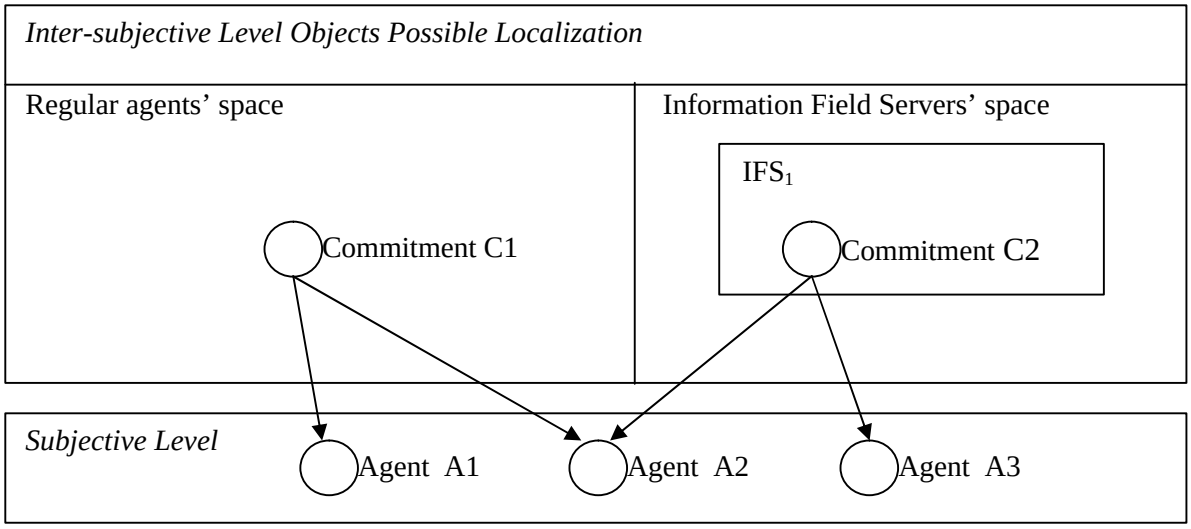

Figure 7: Social objects representation and usage

Conclusions and Future Work

Organizational co-ordination is an activity that requires viewing an organization as made up of normative, role-playing, agents with social obligations and personal interests, which they eventually convert into agent-level intentions and persistent goals that could be pursued using a network of relationships with other agents.

This paper addressed the coordination issue using an intentional normative agent model (EDA) that is supported by a norm classification theory from social psychology, and the concept of information field as the normative support of coordinated groups of agents.

We have described how the EDA model can be used together with information fields to create role-based organizational models and to describe social structures which are commonly seen in practice for the coordination of human activities, namely based on private and public commitments. The advantage of the EDA model is that it can be used uniformly to model individual agents, collective agents and even abstract agents such as roles and information fields.

Coordination usually requires communication. The meaningful unit of communication is the conversation (a sequence of speech acts). However, to be effective, conversations require not only a common communication language but also a common ontology and the mutual

understanding of several normative notions, *i.e.* the context of an information field.

An important aspect of communicative coordination is the pragmatic *intake* of the conversation. A conversation can change one or several components of an agent model (Epistemic, Deontic or Axiological) and it can also produce effects at several levels: agent level, role level or organizational level.

Although a small case study has been implemented, based on a toy problem, using the Java-based communication environment Jini combined with the knowledge representation tool Jess, the next step in the research work that was described here is the implementation of a full scale case study, in order to assess in practice the effectiveness of the proposed theoretical model.

The links to other work in the area of social agent systems will be developed in the near future, especially in relation to the work of Carles Sierra and colleagues, such as (Vasconcelos et al., 2001; Esteva et al., 2001), and also in relation to the work of Dastani et al. (2003) and Dignum (2002a; 2002b), especially related to organizational roles, norms and deontic logic.

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