Towards a Formal Specification of Complex Social Structures in Multi-agent Systems

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Abstract. In this paper we summarize the results obtained so far in the course of the Fishmarket project concerning the study of the formalization, design and construction of agent-mediated electronic institutions (AMIs). We argue that AMIs are the most appropriate social structure for a large variety of multi-agent systems. Here we present the realization of an actual AMI, FM, inspired on the traditional fish market that we employ as a case study in our proposal for the formalization of electronic institutions.

1 Introduction

The notion of interaction between agents makes up the core of all multi-agent systems. Interactions are the observable part of these systems' behaviour: cooperation, coordination, collaboration and negotiation.

Our aim is to build agents that help humans negotiate. Eventually, humans can rely on autonomous agents for their negotiation tasks. However, these must be able to cooperate, not only with other autonomous agents, but also with humans. Consequently, we are interested in the interaction models that take into account the special features of human negotiation. Particularly, as a basic feature, the notion of dialogue, since we consider negotiation, and interaction in general, as a dialogic activity: humans and agents reach agreements through conversations. Because of the interaction between agents and humans no notion of omniscience or perfect rationality can be assumed in the counterparts to our agents.

Dialogic exchanges assume that agents are entities capable of establishing commitments. In negotiation terms, the dialogue participants are in relation with social conventions and institutions that enforce the acomplisment of these commitments. For instance, a separation agreement is established trough a contract which is mediated and validated by a judge; heritage transfers require a registry office and the concurrence of a notary; shares are exchanged at stock markets.

Also note that even though human negotiation can profit from the elucidatory and explanatory resources of conversations, the mediated negotiations in the aforementioned institutions exclude this necessity imposing a strict interpretation of the language used in the dialogue through the conventions established by such institutions. This is the case of price calls in an auction house, or number sequences in a stock market. Similarly, in agent-mediated interactions meaning has to be made explicit. Even though one can imagine that dialogic interactions have an elucidatory content, restricting negotiation —and interactions in general— to those which use perfectly defined languages is a much more practical option. In this work, we consider institutions as the most appropriate social structure for handling the interactions among agents in a large variety of multi-agent systems.

The notion of institution is founded on three pillars which contain the elements already mentioned:

1. *A dialogic framework.* Some aspects of an institution are fixed, constituting the context or framework of interaction amongst agents. In an institution, agents interact trough illocutions. Institutions define which are the acceptable illocutions, which is the ontology —including roles, place and time—, the common language to refer to the "world", a common language for communication, and a common metalanguage. An institution can often consider social relationships between participating agents as relevant —in terms of authority, for instance— or some "personality" feature which can affect the interactions. All of these contextual features are what we call dialogic framework.
2. A *performative structure.* Interactions between agents are articulated through agent group meetings, which we call scenes, with a well-defined communication protocol. We consider the protocol of a scene to be the possible dialogues agents may hold. Furthermore, a performative structure also includes the specification of the transitions between scenes.
3. *Rules of Behaviour.* Agent actions in the context of an institution —as far as we are concerned, dialogic actions or utterances[1]— have consequences; usually commitments which either impose or relax restrictions on dialogic actions of agents in the scenes wherein they will act in the future. Behaviour rules affect the behaviour of agents, or more generally the performative structure.

As a starting point for the study of electronic institutions in the framework of the Fishmarket project, we chose auction houses as a paradigm of traditional human institutions. Auctions are an attractive domain of interest for AI researchers in at least two areas of activity. On the one hand, we observe that the proliferation of on-line auctions in the Internet —such as Auctionline(www.auctionline.com), Onsale(www.onsale.com), eBay(www.eBay.com) InterAUCTION(www.interauction.com), and many others— has established auctioning as a main-stream form of electronic commerce. Thus, agent-mediated

[1] "utterance suggests human speech or some analog to speech, in which the message between sender and addressee conveys information about the sender" [15]

auctions appear as a convenient mechanism for automated trading, due mainly to the simplicity of their conventions for interaction when multi-party negotiations are involved, but also to the fact that on-line auctions may successfully reduce storage, delivery or clearing house costs in many markets. This popularity has spawned AI research and development in computational auction markets [24, 19] as well as in trading agents and heuristics [5, 8]. On the other hand, auctions are not only employed in web-based trading, but also as one of the most prevalent coordination mechanisms for agent-mediated resource allocation problems (f.i. energy management [26, 25], climate control [6], flow problems [22]).

The rest of the paper is organized as follows. In Section 2, we describe a traditional trading institution, the fish market, along with the essential notions of how its electronic counterpart (FM) works. Then a proposal for a formalization of electronic institutions follows in Section 3. Next Section 4 introduces the first attempts towards the realization of such a formal specification based on the usage of interagents. Finally, Section 5 presents some conclusions and outlines some challenging issues to be faced as future work.

2 The fish market: A Case Study of Human Institutions

Traditional trading institutions[2] such as auction houses —and the fish market in particular— have successfully dealt with the issues of diversity (of goods, trading conventions, participants, interests) and dispersal (of consumers and producers, and also of resources and opportunities). For instance, by defining strict trading conventions where goods of specified kinds (e.g. fish of certain quality) are traded under explicit time/location restrictions (e.g. twice a day at fixed times at the fish market building) under strict negotiation protocols (e.g. downward bidding[3]). Participating agents are subject to terms and conditions —involving identity, credit and payment, guarantees, etc.— whereby the soundness of transactions becomes a responsibility of the institution itself, who in turn enforces those terms and conditions on its own behalf.

From our view, the fish market can be described and modelled as a place where several *scenes* run simultaneously, at different places, but with some causal continuity[19, 12]. The principal scene is the auction itself, in which buyers bid for boxes of fish that are presented by an auctioneer who calls prices in descending order —the *downward bidding protocol*. However, before those boxes of fish may be sold, fishermen have to deliver the fish to the fish market, at the *sellers' registration scene*, and buyers need to register for the market, at the

[2] We use the term *institution* in the sense proposed by [14] as a "set of artificial constraints that articulate agent interactions".

[3] The Spanish fish market still uses the traditional *downward bidding* protocol in which boxes of fish are adjudicated to the buyer who *stops* a descending sequence of prices that is called by an auctioneer in front of all registered buyers. This protocol is also called a *Dutch auction* because it is the way flowers have been traditionally traded in Holland. For historical references and the classical economic-theoretical outlook on auctions, cf., [9, 10].

buyers' registration scene. Likewise, once a box of fish is sold, the buyer should take it away by passing through a *buyers' settlements scene*, while sellers may collect their payments at the *sellers' settlements scene* once their lot has been sold. Each scene is supervised by one of the market intermediaries (auctioneer, buyer admitter, buyer manager, seller admitter, seller manager, and boss) which represent and work for the institution.

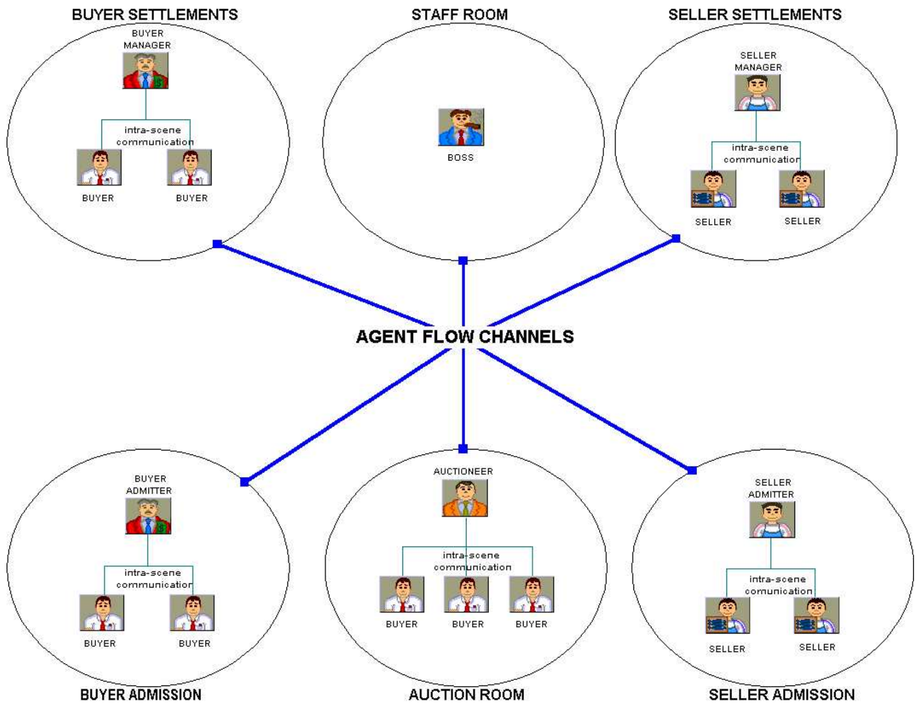

Fig. 1. FM Multi-scene Structure

In practice, the fish market upholds the fairness of the negotiation process and the accountability of transactions by defining and enforcing stable conditions on:

- the eligibility requirements for participating buyers and sellers;
- the availability, presentation and delivery of goods;
- acceptable behaviour of participants within the site; and
- the satisfaction of public commitments made by participants.

We believe that similar functions may advantageously be instituted for multi-agent systems. This mimetic strategy lead to a *proof of concept*-level electronic auction house presented in [11], and subsequently refined in order to produce

FM96.5 [19], a rather complete implementation of the actual fish market. Later on FM96.5 was extended in order to obtain a test-bed for trading agents, FM (see [17] and [18] for a more thorough discussion)[4].

In a highly mimetic way, the workings of FM also involve the concurrency of several scenes governed by the market intermediaries identified in the fish market. Therefore, seller agents register their goods with a seller admitter agent, and can get their earnings (from a seller manager agent) once the auctioneer agent has sold these goods in the auction room. Buyer agents, on the other hand, register with a buyer admitter agent, and bid for goods which they pay through a credit line that is set up and updated by a buyer manager agent. Figure 1 shows the conceptual model of FM as a multi-scene multi-agent scenario. We regard each scene as a virtual scene inhabited by agents that might be physically running at different sites. Observe also that we draw a distinction between *agent flow*, corresponding to buyers and sellers (henceforth trading agents) moving from scene to scene, and *communication flow*, corresponding to both the interaction between trading agents and market intermediaries and the interaction among market intermediaries aiming at the coordination of their activities. Notice also that agents cannot enter any scene because the institution imposes constrains on the transitions between scenes (f.i. a buyer cannot leave the auction room for entering the admission room).

The main activity within FM, the auctioning of goods in the auction room, is governed by the auctioneer making use of the downward bidding protocol (DBP) that next we state explicitly:

[**Step 1**] The auctioneer chooses a good out of a lot of goods that is sorted according to the order in which sellers deliver their goods to the sellers' admitter.

[**Step 2**] With a chosen good g, the auctioneer opens a *bidding round* by quoting offers downward from the good's starting price, (p_α) previously fixed by the sellers' admitter, as long as these price quotations are above a *reserve price* (p_{rsv}) previously defined by the seller.

[**Step 3**] For each price called by the auctioneer, several situations might arise during the open round:

Multiple bids Several buyers submit their bids at the current price. In this case, a collision comes about, the good is not sold to any buyer, and the auctioneer restarts the round at a higher price. Nevertheless, the auctioneer tracks whether a given number of successive collisions (Σ_{coll}) is reached, in order to avoid an infinite collision loop. This loop is broken by randomly selecting one buyer out of the set of colliding bidders.

One bid Only one buyer submits a bid at the current price. The good is sold to this buyer whenever his credit can support his bid. Whenever there is an unsupported bid the round is restarted by the auctioneer at a higher price, the unsuccessful bidder is punished with a fine, and he is expelled out from the auction room unless such fine is paid off.

[4] The current version of FM [16] is now available and can be downloaded from the Fishmarket project web page [27]

No bids No buyer submits a bid at the current price. If the reserve price has not been reached yet, the auctioneer quotes a new price which is obtained by decreasing the current price according to the price step. If the reserve price is reached, the auctioneer declares the good *withdrawn* and closes the round.

[**Step 4**] The first three steps repeat until there are no more goods left.

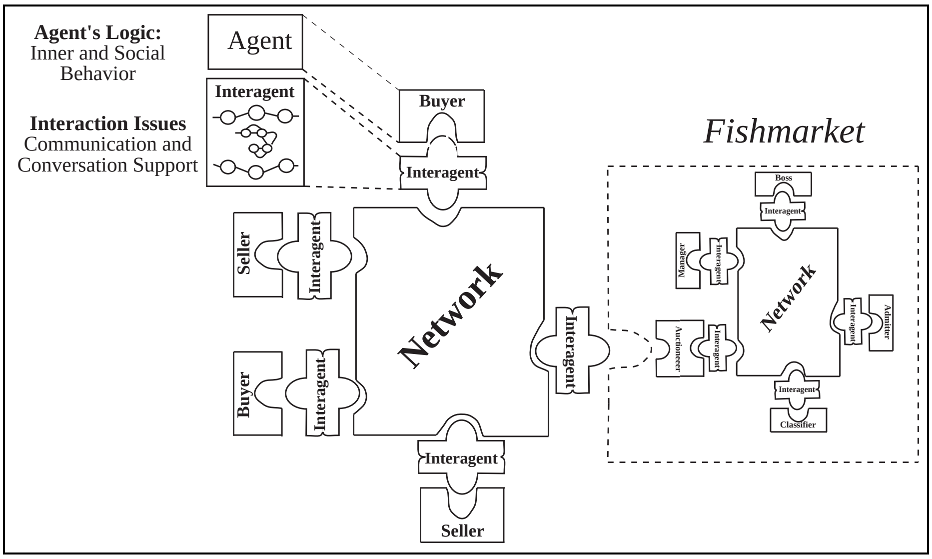

Fig. 2. *Fishmarket*: A multi-agent system using interagents

Analogously to the actual fish market, FM must be regarded as an *electronic institution* wherein heterogeneous (human and software) agents of arbitrary complexity can trade goods as long as they comply with the *fish market institutional* conventions. Those conventions that affect buyers and sellers are enforced by a special type of software agents owned by the institution, the so-called *interagents*, that establish what utterances can be said by whom and when. They constitute the unique mean through which trading agents interact within the market scenario (see Figure 2). Thus, as a rule, agents' external behaviour is managed and mandated by interagents, while their individual logic, knowledge, reasoning, learning, or other capabilities are internal to agents. A thorough description of interagents appears in Section 4.

3 A Formal View of Agent-mediated Electronic Institutions

Throughout this section we elaborate a proposal for formalizing electronic institutions taking inspiration on the example of electronic institution presented above. Thus we must first remember that we based our notion of electronic institution on three pillars (dialogic framework, performative structure, rules of behaviour) that we formally define in what follows.

First, we observe that each agent participating in an institution takes on a role. Consequently, the notion of *role* is a core concept for our model of institution. Henceforth we denote the role set of an institution as *Role*. From this we can define a partial order over *Role* to capture the notion of authority (f.i. $r_i \geq r_j$ means that role r_i has authority over role r_j).

From [13, 20] we take that the central notion for defining the ontologic elements employed during an agent interaction is a *dialogic framework*. Since these ontologic elements depend on each role, we define a dialogic framework as:

Definition 1. Given a role set *Role*, a *Dialogic Framework* is a family of tuples $DF_r = (L_r, ML_r, \iota_r, Time)$ for each $r \in Role$ where

- L_r is a language for the domain of role r;
- ML_r is a metalanguage on L_r;
- ι_r is the illocution set of role r; and
- $Time$ is a discrete and totally ordered set of instants.

Considering the example of an electronic auction institution introduced in Section 2, we have that:

- $Role$ = {auctioneer, buyer admitter, buyer manager, seller admitter, seller manager, boss, buyer, seller}
- $boss \geq r$ for all $r \in Role$
- $r \geq buyer$ and $r' \geq seller$ if $r \in Role - \{seller\}$ and $r' \in Role - \{buyer\}$
- $L_{auctioneer} = \{good(id, type, weight), lot(id), sold(buyer\_id, price), offer(price), \ldots\}$
- $L_{buyer} = \{good(id, type, weight), bid, offer(price), admission(scene), \ldots\}$
- $\iota_{auctioneer} = \{question, request, inform, commit, refuse\}$
- $Time = \mathbb{R}$

We assume in this work that each agent keeps its role regardless of the scene in which it participates.

Be now Ag a finite agent variable set, and $As : Ag \longrightarrow Role$ the function which assigns to an agent variable an agent role. Then, we build the communication language as the set of all legal (allowed) illocutions between agents:

$CL = \{\iota_{As(x)}(x, y, \varphi_{As(x)}, t)\}$ where $x, y \in Ag$, $\varphi_{As(x)} \in L_{As(x)}$ and $t \in Time\}$

Then the institution's language L_I is formed in the usual way from CL and the $\wedge, \vee$ and $\neg$ connectives —which stand for the conjunction, disjunction and negation respectively. Given R a subset of roles, the L_I sublanguage with respect to R, denoted as L_R, is composed of the formulae with agent variables whose roles belong to R.

Next we provide an example of illocutions within the communication language and the institution's language for FM corresponding to a price called by the auctioneer during a bidding round:

- $inform(auctioneer, buyer_i, offer(1300), 17:00) \in CL$
- $\bigwedge_{k=0\ldots n} inform(auctioneer, buyer_k, offer(1300), 17:00) \in L_I$

The notion of performative structure is the most complex and interesting of this formalism, since it models the whole dialogic activity within an institution. The definition is based on the notion of scene that we present next. Conceptually, a scene is the specification of a conversation involving a group of agents. And formally,

Definition 2. A scene is a tuple $s = (R, G_e, W_i, W_f)$ where

- R is a multi-set[5] formed by elements of *Role*;
- $G_e = (W, A, Es)$ stands for a directed and labelled graph, where W is the set of states, $A \subseteq W \times W$ is the set of directed edges, and $Es : A \longrightarrow L_R$ is the labelling function;
- $W_i \in W$ is the non-empty scene state, and
- $W_f \subseteq W$ the final states of the scene.

Thus a scene is a directed graph labelled by language statements of L_I whose vertices stand for the states of the conversation and whose edges stand for transitions between such states. Given a particular state of the scene w and a transition(labelled edge) to an adjacent state w', we say that the transition occurs when the formula f labelling the edge is satisfied (the labelling function Es outputs the formula to be satisfied in order to go from one state to the the other, so $Es((w, w')) = f$). At every non-final state of the scene there is at least one transition to another state. A scene is considered to be finished when it reaches one of its final states. Note that the transition and state sets determine the scene's protocol, i.e. the possible dialogic interactions.

If we want a scene to be deterministic the following restriction must be imposed: given a state, the same formula cannot lead to different states, therefore Es must satisfy: $Es((w, w')) \not\equiv Es((w, w''))$ where $\not\equiv$ means that the formulae are not equivalent.

Observe also that the definition of scene does not depend on agents, but on their roles. Then a scene can start whenever there is a role assignment, i.e. there is a group of agents capable of assuming the roles specified by the scene. Note that an institution may allow for the simultaneous execution of more than one scene with different groups of agents.

A complex social structure, as is the case of an institution, is formed by multiple interrelated scenes which are executed either concurrently or sequentially. Establishing the interrelations among scenes amounts to specifying how

[5] A multi-set is a set where elements may be repeated.

and when agents leave and enter scenes. Restrictions imposed on this agent flow determine the flexibility of the formalism. For this purpose we define the notion of transition between scenes as the specification of the conditions that an agent must verify to leave a scene and enter another.

Definition 3. A transition tr is an ordered pair of statements of the metalanguage ML, i.e., $tr = (Pr, Po)$ where Pr and Po are the precondition and postcondition sets (written in the metalanguage)

We define the metalanguage ML as the set of all metalanguages ML_r, and T denote the set of all transitions. Both preconditions and postconditions refer to the state of the scenes, the role of the agents, etc.

Now it is time to define the fundamental notion of performative structure.

Definition 4. Given a dialogic framework $(DF_r)_{r \in Role}$, a performative structure is a directed graph labelled by transitions with scenes as vertices. Formally, $PS = (S, A, Et)$ where

- S is a finite and non-empty set of scenes.
- A is a set of edges, i. e., $A \subseteq S \times S$.
- Et is a labelling function,i.e., $Et : A \longrightarrow T$.

Back to our example based on FM, we may define the following examples of performative structure:

- $S = \{$buyer admission, buyer settlement, auction room, seller admitter, seller settlement, out of market$\}$
- $A = \{$(buyer admission,auction room),(auction room,buyer settlement),...$\}$
- Et((buyer admission,auction room)) = ($\{$As(x) = buyer, admitted(x) = true$\}$, $\{$scene_state(auction_room) = init$\}$)
- $PS_1 = (S, A, Et)$
- $PS_2 = (S' = S - \{$buyer admission,seller admission$\}, A_{|S'}, Et_{|S'})$

The transition above indicates how an agent can leave the buyer admission scene to enter the auction room scene. In general, we shall consider that an agent can leave a scene:

- when requesting for leaving, it fulfils the transition conditions between scenes;
- if an agent with superior authority orders so; and
- if the scene reaches a final state.

There remains the matter of defining where the agent is incorporated into another scene once a transition occurs. There are essentially two options:

- in the current state of the scene; and
- in a predetermined entrance state of the scene —in this case the agent must wait until the scene reaches such state.

More concretely, let x be an agent in scene s, if x wants to move from s to s', and we assume that $(s, s') \in A$ and $Et((s, s')) = tr$, then the following procedure must be followed:

- if x does not satisfy the tr preconditions then the entrance to s' is denied;
- if x satisfies the tr preconditions then:
  - if s' satisfies the postconditions the entrance is permitted; and
  - if s' does not satisfy the postconditions the entrance is denied until these are satisfied.

We understand that the agent's speech acts introduce subsequent acting commitments that have to be interpreted as acting obligations in a certain direction, and, consequently, as a limitation or enlargement in the acting possibilities. In particular, this implies imposing or removing restrictions on the inter-scene transitions of the agent acquiring the commitments or, in a more general sense, producing changes in the performative structure. In this approach we formalize such commitments with the so-called *behaviour rules* that we define as:

Definition 5. Given a dialogic framework $(DF_r)_{r \in Role}$ and a set of performative structures $\mathcal{PS}$, a behaviour rule RB is a function of the form: $RB : L_I \times \mathcal{PS} \longrightarrow \mathcal{PS}$

Following the example above, the rule of behaviour below makes explicit the change in the performative structure (closing both the buyer and seller admission scenes) when the boss declares that the market is closed.

$$RB(inform(boss, sellermanager, close\_market(now), 17:30), PS_1) = PS_2$$

Finally, we can define an electronic institution by grouping together all the elements introduced so far:

Definition 6. An electronic institution is a triplet $EI = ((DF_r)_{r \in Role}, \mathcal{PS}, \mathcal{RB})$, where $(DF_r)_{r \in Role}$ is a dialogic framework, $\mathcal{PS}$ is a set performative structures and $\mathcal{RB}$ is a set of behaviour rules.

Only left to remind that the execution of an institution consists on the generation of scene instances, the allocation of specific agents to the agent variables to roles of a scene, and the movement of agents through scenes respecting the transitions given in the performative structure, and the evolution of the performative structure specified by the rules of behaviour.

4 On the Implementation of AMIs: an Interagent Approach

In [7] we introduced interagents as autonomous software agents that mediate the interaction between an agent and the agent society wherein this is situated. In this section we sketch out their functionality and we discuss how they have been employed for realizing the particular formal specification of the fish market.

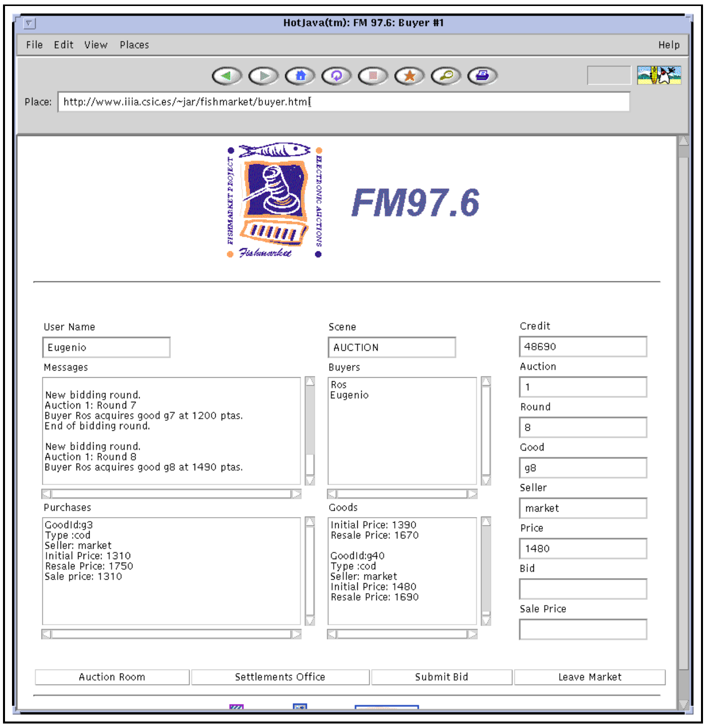

Fig. 3. *GUI offered by an interagent to a human buyer*

The management of *conversation protocols*(CPs) was identified in [7] as the main task of interagents. We view conversations as the means of representing the conventions adopted by agents when interacting through the exchange of utterances [23, 3]. More precisely, such conventions define the *legal* sequence of utterances that can be exchanged among the agents engaged in conversation: what can be said, to whom and when. Therefore, CPs are coordination patterns that constrain the sequencing of utterances during a conversation held between two agents.

We differentiated two roles for the agents interacting with an interagent: *customer*, played by the agent exploiting and benefiting from the services offered by the interagent; and *owner*, played by the agent endowed with the capability of dynamically establishing the policies that determine the interagent's behaviour. Needless to say that an agent can possibly play both roles at the same time. An interagent is responsible for posting utterances of its customer to the corresponding addressee and for collecting the utterances that other agents address to its customer. This *utterance management* abstracts customers from the details concerning the agent communication language and the network protocol. Each interagent owns a collection of relevant CPs used for managing its customer conversations. When its customer intends to start a new conversation with another

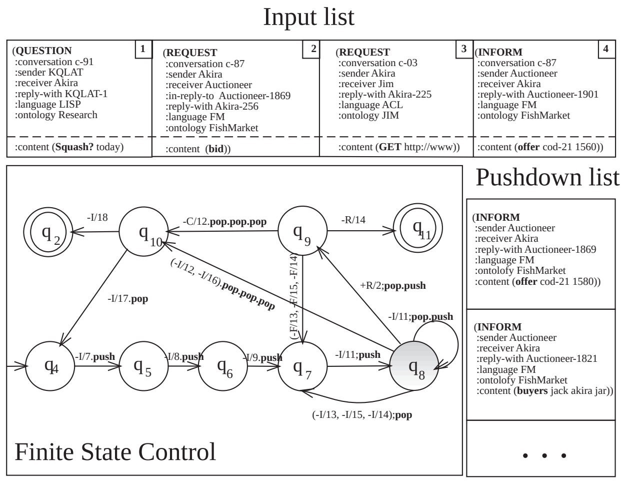

Fig. 4. View of the CP used by buyers' trading interagents in the auction room.

agent the interagent instantiates the corresponding conversation protocol. Once the conversation starts, the interagent becomes responsible for ensuring that the exchange of utterances conforms to the CP specification.

#Message	Predicate	Parameters
1	*admission*	*buyerlogin password*
2	*bid*	[*price*]
3	*exit*	

Table 1. Trading Interagent Incoming Predicates

We shall differentiate two types of interagents in FM: *trading interagents*, owned by the institution but used by trading agents, and *institutional interagents*, both owned and used by those agents functioning as market intermediaries. Therefore, all interagents are owned by the institution, but we identify two types of customers: the trading agents and the institution itself.

Trading interagents constitute the sole and exclusive means through which trading agents interact with the market intermediaries representing the institution. Within each scene, a trading interagent must employ a different CP to allow its customer to talk to the market intermediary in charge of it. Therefore, trading interagents are responsible for enforcing the protocols that guarantee that every trading agent behaves according to the rules of the market.

As to market intermediaries, they must hold several conversations at the same time with the agents in the scene that they govern. For this purpose, the institutional interagents that they employ must exploit their capability for supporting multiple conversations by building collections of simultaneous CP

#Message	Predicate	Parameters
4	*deny*	*deny_code*
5	*accept*	*open|closed auction_number*
6	*open_auction*	*auction_number*
7	*open_round*	*round_number*
8	*good*	*good_id good_type starting_price resale_price*
9	*buyers*	$\{buyerlogin\}^*$
10	*goods*	$\{good\_id\ good\_type\ starting\_price\ resale\_price\}^*$
11	*offer*	*price*
12	*sold*	*good_id buyerlogin price*
13	*sanction*	*buyerlogin fine*
14	*expulsion*	*buyerlogin*
15	*collision*	*price*
16	*withdrawn*	*good_id price*
17	*end_round*	*round_number*
18	*end_auction*	*auction_number*
19	*going*	$\{single\|multiple\} + \{1, 2\}$
20	*gone*	
21	*tie_break*	*buyerlogin*
22	*closed_market*	

Table 2. Trading Interagent Outgoing Predicates

instances (one per trading agent). Thus, for example, the auctioneer's interagent maintains an instance of the CP corresponding to the DBP for each buyer agent in the auction room. Moreover, not only are institutional interagents used to support conversations with trading agents, but also to allow those agents working as market intermediaries to coordinate their activities.

Anyhow, notice that an interagent does not handle the whole graph encoding all the interactions permitted within a scene, but a CP obtained as a projection of the graph corresponding to the role of its user.

The finite state control of the CP employed by the interagent for allowing its customer (a buyer agent) to participate in a bidding round in the auction room is depicted in Figure 4. For the sake of simplicity, the arcs of the finite state control are labelled with the predicates in Tables 4 and 2, corresponding to the propositional content of the utterances permitted by the CP. The diagram displays the interaction between a buyer agent and his interagent from the agent's view. Therefore, message numbers followed by / stand for messages sent by a buyer agent, while message numbers preceded by / stand for messages received by a buyer agent. For instance, 2/ means that the buyer submits a bid at the price called by the auctioneer within /11. Note that that trading interagents handle differently their interaction with human customers. In such a case, they offer a GUI for the human traders to interact (see Figure 3).

There still remains the matter of capturing the central notion of performative structure, i.e. the transitions of agents between scenes. Trading interagents in FM allow their users to jump from one scene to another by connecting each final state in a CP with the initial state of the CP corresponding to the destination scene. However the actual peformative structure required by FM is hard-wired into interagents, which are not capable yet of handling specifications of performative structures.

Interagents have been endowed with further capabilities. On the one hand, they are in charge of conveying monitoring information to the auditing agent (also called monitoring agent), so that market sessions can be monitored, and analyzed step-by-step. On the other hand, interagents provide support for agent failure handling. For example, when a trading agent either goes down or simply fails to consume the utterances conveyed by its interagent (say that the trading agent lapses into an extremely demanding deliberative process for elaborating its strategies), this interagent pro-actively unplugs its customer from the market and leaves the market on its behalf.

Finally, the interagents in FM can dynamically (at run-time) reconfigure CPs in order to guarantee the verification of the liveness, termination, and the deadlock and race condition free properties in order to ensure protocol compatibility.

Summarizing, the successful incorporation of interagents into FM has proven their usefulness by coping with several tasks: i) to handle the interplay between trading agents and the market institution; ii) to handle the coordination between market intermediaries' tasks; iii) to provide support for the monitoring of market sessions; iv) to handle agents' failures; v) to reconfigure CPs so as to ensure protocol compatibility. Ideally further, gradual extensions of interagents' capabilities will permit coping with the required functionalities of an AMI.

5 Conclusions and Future Work

Up to date not much work has attempted to employ organizational approaches for the specification and design of multi-agent systems [4]. We argue that the use of organizational concepts (such as roles, groups or institutions) can prove to be valuable for the deployment of complex social structures in multi-agent systems. In this work we summarize the contributions in this direction made in the course of the Fishmarket project concerning the study of the formal specification, design, and construction of a special type of multi-agent systems: agent-mediated electronic institutions (AMIs). We exemplify our current conceptualization of electronic institution by means of an actual implementation, FM, an electronic auction house inspired on the traditional fish market. Such an example also serves to identify the fundamental components of an electronic institution that are subsequently employed for elaborating a proposal for formalizing electronic institutions, along the lines of [21] that provides solid foundations for the design of a specification language. There are still several open issues concerning our formal view:

- how to allow that agents play different roles within different scenes;

– how to allow that agents participate in different scenes at the same time; and
– how to allow for the multiple instantiation of the same scene.

These features will surely lead to a much more flexible formalization of electronic institutions so that a wider range of practical institutions can be covered.

Therefore our future work is to concentrate on the completion of a stable formalization that leads to the design of a (both graphical and textual) specification language for electronic institutions ([2] accounts for the first attempts in this direction). Ideally such a language shall support the automatic generation of electronic institutions as well as some of their participating agents. For instance, such a language would permit to specify an auction house in order to obtain the infrastructure (conversation protocols and interagents in the sense proposed in [7]) required for ensuring a sound multi-agent trading interaction. For this purpose, the specification language must address a fundamental issue: the generation of the CPs to be managed by interagents from the specification provided by the institution designer.

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