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Auctions and Multiagent Systems

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Abstract

In an auction house, buyers and sellers coordinate so as to exchange goods following a highly structured and apparently simple procedure. These coordination conventions have evolved through the years, and are currently used in commercial institutions for exchanging diverse goods and services. In this chapter we take as an instance a traditional auction house, the *Llotja* (a fish market) of Blanes, and we discuss how a virtual and adaptable electronic fish market can be derived from it. In this virtual institution the mediating functions are performed by autonomous agents, and customers or vendors can be either individuals or software agents. We also show how the underlying notions can be applied to define other institutions where the participants can be software agents.

1 Introduction

According to some economists (for instance, Cassady [2] or Wolfstetter [46]), auctions are price-fixing mechanisms in which negotiation is subject to a very strict coordination process. Buyers and vendors take part in this process, but the exchange is done through a mediator —the auctioneer— who presents the goods to exchange and makes (or receives) offers for such goods following a pre-established *bidding convention* which determines the sequence of offers as well as the way to decide the winner and the price to be paid by the winner. For instance, in the traditional Spanish fish markets a so-called "downward bidding" convention is followed. In it, the auctioneer typically signals a fish crate, declares an initial price, and starts singing a fast sequence of descending prices until a buyer says 'mine', thus indicating his/her acceptance of the last price sung.

Other economists (such as Smith [38] or McAfee and McMillan[15]), however, refer to auction houses as *institutions* [21] and are careful to point out that, in

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addition to the bidding conventions, other equally relevant conventions and elements are used in an auction house to achieve a proper co-ordination of buyers and sellers: conventions for the registration of participants and goods, conventions on guarantees and payment, commissions, starting prices, etc..

The approach adopted in this chapter is closer to the latter view of an auction, although we imbue this view with elements from artificial intelligence. An auction house is viewed as an *institution* where three types of conventions are defined and enforced:

1. **Ontologic and Communicational Conventions** in which all the elements which form an auction and the meaning of the illocutions exchanged are clarified.

2. **Social Conventions** which regulate the interactions among participants in an auction while they are taking part in it.

3. **Individual Behaviour Rules** to which the participants in an auction are subject and which establish the commitments, obligations and rights which concern them.

Through these conventions, an auction house imposes objective conditions which concern:

- The availability, presentation and delivery of goods,
- the admission requirements for buyers and sellers,
- the behaviour rules for participants in an auction, and
- the fulfilment of public commitments acquired by participants in an auction.

By imposing such conventions, the institution articulates the interactions between buyers and sellers establishing and warranting that negotiations and transactions are carried out in a fair and transparent manner.

Furthermore, in this chapter we are concerned not with traditional auction houses, but with a sort of *virtual institution* that serves the same purpose. A traditional auction house and its virtual institution counterpart are essentially the same, but for two key differences. On the one hand, whereas the place where auctions are carried out in a traditional institution is a physical place, the virtual auction is carried out in a *virtual* location. On the other hand, participants in a traditional auctions are usually called *agents*, but in contrast we allow agents taking part in a virtual institution to be not only humans but also software agents[1]. Consequently, this virtual institution could be understood (in an abstract sense) as a *multiagent system model*, or more specifically, as its *computational realization in the Internet*.

[1] Note that we distinguish between *auction house* (an institution which carries out auctions), and *auction* (the *process* of goods exchange subject to the conventions of an auction house or to an *instance* of that process). We also distinguish *bidding conventions* (those to regulate only the negotiation *rounds* of an auction) and the *auction* conventions (which regulate other sections or scenes in addition to rounds). In this article we will only refer to *sale* auctions (or "round off"), but everything said can also be applied to *purchase* auctions (or "procurement").

Considering the computational realization of an institution in which agents take part allows focusing attention on an obvious, though not trivial, aspect of this realization: *agents interact exclusively through message exchange*. These messages can be built with illocutions in a formal language, and thus, the interaction between agents in a virtual institution becomes an illocution exchange. We call this observation the *strong dialogical stance* and it means supposing that the multiagent system which models the institution is a *dialogical system* (in the sense it is understood by Hamblin [9][2]). In practice, this means saying that any commitment which could be admitted as a *valid commitment* in a virtual auction house will correspond with a message which was uttered by a participant and received by another (or another group of participants) during the auction, according to the rules established by the institution. Formally speaking, as far as we are concerned, an "agent" will be "an entity capable of establishing commitments" and every commitment adopted in a virtual institution will correspond either to a pre-condition or a post-condition of an illocution exchanged by agents according to the institution's rules of interaction.

In this chapter we will show how a traditional auction house can inspire a virtual institution which adapts its traditional coordination conventions to the current conditions of electronic commerce. We will first concentrate (Section 2) on the social conventions for the virtual institution and later on the individual rules of behaviour to which participants are subject; we will see the commitments these dialogical exchanges lead to and discuss some classical variants of this protocol. Later, in Secc. 3, we will indicate how it is possible to formalize these ideas in a *virtual institution* and we will mention the computational realization of the Fishmarket. Finally, in S.S. 4 and 5 we will mention how these specific examples can be generalized to build other virtual institutions inhabited by agents that mediate, and interact with other participants which can be either humans or software agents.

Note that our approach is mainly descriptive, and that we will not mention any of the predictive aspects. Nevertheless, these are very frequent in auction literature, so much in the one called by economists *Mechanism design* as in the auction literature of the A.I. community that usually includes them in the *Market-based Programming*. In Mechanism Design, the objective is, essentially, to identify these coordination conventions (certainly auctions, but also double auctions, stock markets and, in general, different types of structured negotiation) which warrant certain optimality conditions or "balances"; or exploring the consequences of adopting alternative conventions —in those balances— under suppositions on the rationality of participants, the offering of goods or the participants expectancies (Cf. Mas-Colell *et al.* [14] or Varian [42], for more theoretical approaches; Paarsch [10] for the experimental ones). In Market-based Programming, on the contrary, techniques and results of the Economic Theory are used to resolve programming problems in which the market metaphor is happily evoking (Cf. Wellman [45] and Clearwater [4]); for instance, the task assigning (through auction) between a network's processors (Smith and Davis [37], Mullen y Wellman [17]) or the partitionable data base storing (Schwartz and Kraus [32]); or the identification of problems in which a certain auction type cannot be applied (Sandholm [30]) and, particularly, those which directly

[2] See Noriega [19, Ch.4] for a detailed discussion on this point and the corresponding references.

concern the software agent's coordination (e.g. Sandholm and Lesser [31]).

Even though analytic modelling is feasible in the Fishmarket framework (as indicated in [28] and in [29]) our approach is more related to proposals such as *Magnet* [39, 5], *Kasbah* [3] and *Bazaar* [8]. In these proposals the creation of virtual markets in which participants may rely on software agents for some purchase/selling activities is examined. Our approach is also related to the recent proposals of the *AuctionBot* project (<http://auction.eecs.umich.edu>) which involves an "auction server" which allows the activation of on-line auctions, whose conventions can be very flexibly specified and in which it would even be possible to participate with self-made software agents. The content of this chapter reformulates some of our research group's previous papers, in particular [19] and is an adequate introduction to more recent works such as [28].

2 The Fishmarket

In the sections below we will show how it is possible to build a virtual institution, the Fishmarket, which corresponds to a given traditional fish auction in a small fishermen's village.

2.1 Scenes and Performative Structure

The fish market ('Llotja') which currently exists in Blanes (Girona), may be understood as an institution in which a series of scenes involving agents with clearly defined roles or behaviour patterns are *performed*. In Blanes there are five basic scenes, each of which has a characteristic *location* and is coordinated by a member of the Llotja staff. The seller admitter (**sa**) is in charge of the reception of products from sellers in the corresponding zone (**RR**), while the buyer manager (**bm**) is in charge of updating the buyer's credits and delivering the goods to the delivery room (**DR**), etc. (See Figure 1).

Each scene in the Llotja is subject to a strict *protocol* that the staff member must comply with and uniformly enforce upon all external agents.

For instance, the central scene of an auction —the bidding round proper— is carried out in the "auction room", is controlled by the auctioneer and, in the case of the Fishmarket, follows the protocol depicted in Figure 2[3].

This protocol reflects the actual peculiarities of the Blanes auctions, but it has been adapted to the fact that in Fishmarket the participants can be computer programs executed in a remote location. Thus, for instance, the basic bidding convention of the fish market is that the first *valid* offer is the one to win the round[4]. It is acceptable for instance, that buyers and sellers attend the auction, enter and exit the market at will but whereas in Blanes buyer and seller traffic is constant and free, in Fishmarket the (virtual) room

[3] Nodes stand for the states (of the commitments) of the participants, the squares stand for scenes. Arcs are labelled by illocutions (which are abbreviated in the diagram due to space limitations, but they appear complete in Table 1) and the arrows signal origin. Note that every illocution has the structure $\iota(\alpha, \Gamma : \varphi; \tau)$ where ι is an illocutionary particle, α is the agent uttering the illocution; Γ is the set of listeners; φ is the propositional content of the illocution (the message) and τ the moment in which the illocution is produced (which we will consistently omit in this chapter).

[4] An offer is valid if the bidder has enough credit to pay for that bid. If this condition is not fulfilled, infractors are fined or expelled, and the good is auctioned again at a price a percentage higher than the invalid offer.

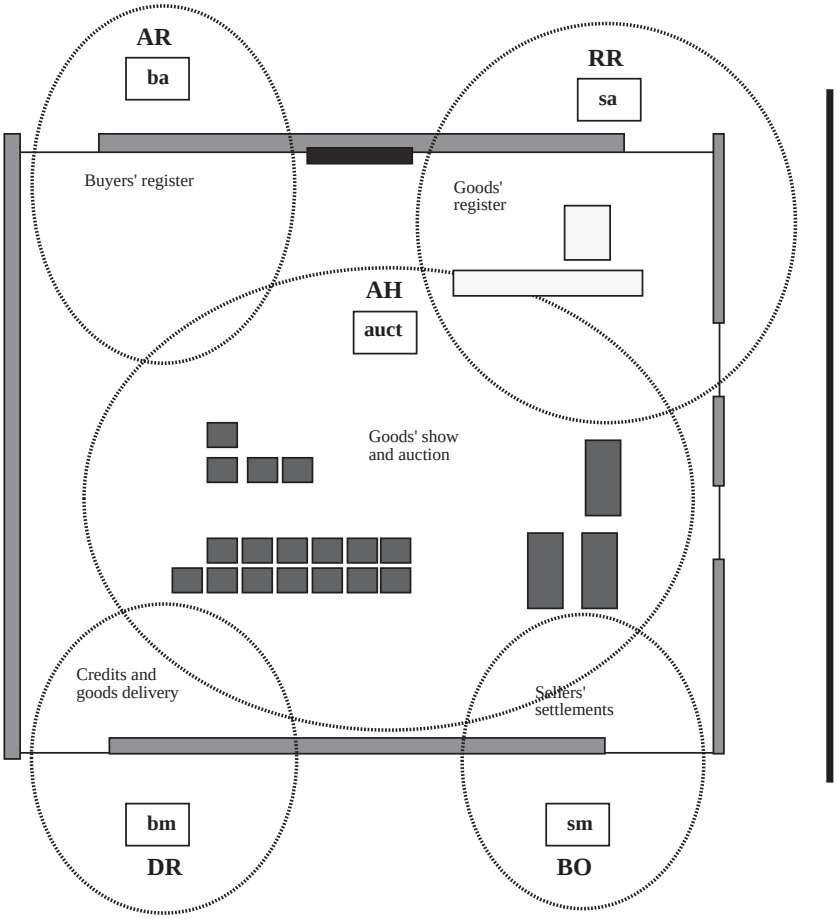


Figure 1: Scenes in the Blanes Llotja.

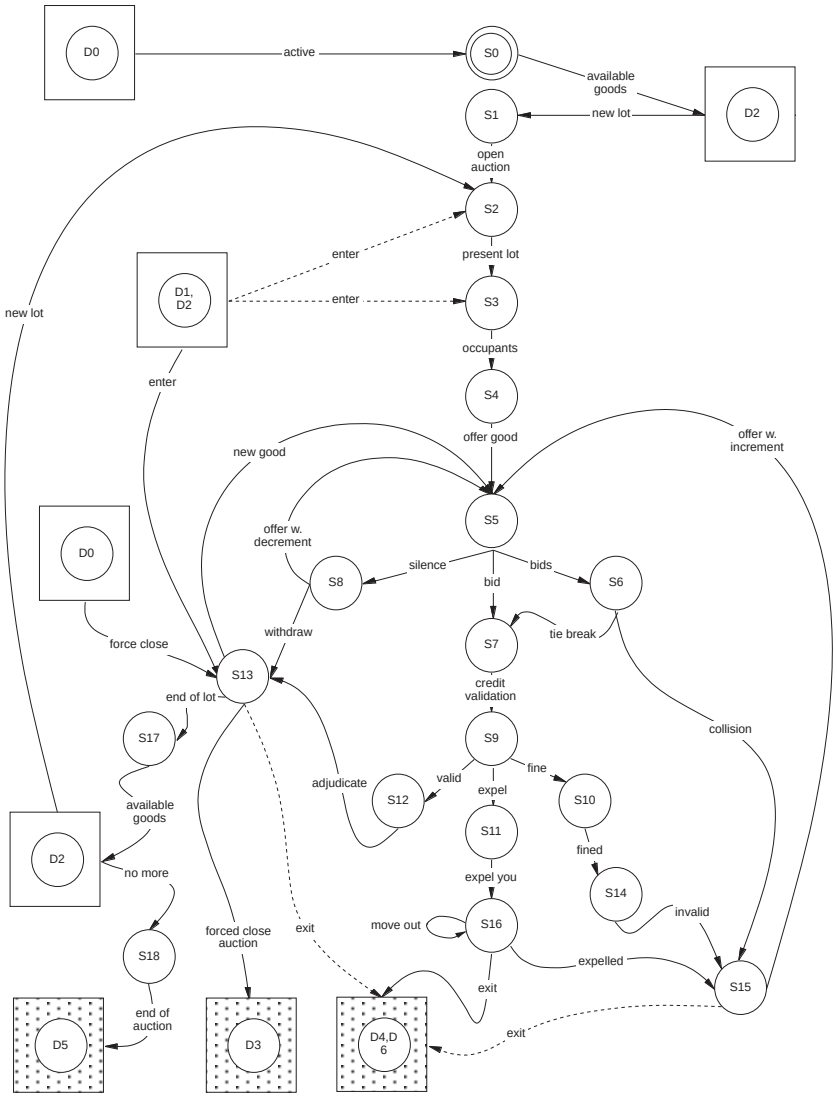


Figure 2: Fishmarket bidding rounds.

$offer(auct, all : tosell(g, p))$
$assert(b, auct : bid)$
$request(auct, bm : creditstatus(b, p_t))$
$assert(bm, auct : valid(b))$
$assert(bm, auct : fined(b, fine))$
$request(bm, auct : expel(b))$
$declare(auct, all \cup \{bm\} : sold(g, b, p, t_\omega))$
$declare(auct, \{b, bm, ba\} : expelled(b))$
$command(auct, b, outto(DR))$
$declare(auct, all : expelled(b))$
$declare(auct, b : fined(b, \kappa))$
$declare(auct, all : invalidbid)$
$declare(auct, all : collision(g, \bar{b}, p))$
$declare(auct, all : tiebreak(\bar{b}, b))$
$declare(auct, all : endoflot)$
$request(b, auct : exitto(DR))$
$request(s, auct : exitto(BO))$

Table 1: Illocutions used in an upward bidding round in the Fishmarket.

is "closed" while the round is in process (to guarantee equity). Another subtle and illustrative difference may be seen in the way collisions are managed in the Fishmarket. In Blanes, in the event of two buyer's offers coinciding at a given price a "tie" is declared and the good is reauctioned at an increased price. However, in the Fishmarket the number of consecutive ties between two or more buyers must be limited somehow, since there may exist a real possibility that two or more software agents maybe implementing the same heuristics (and thus could cause an infinite sequence of collisions). In a real fish market, participants seldom coincide more than once, and the auctioneer acts discrectionally to break any anomalous tie. In the Fishmarket, repeated ties are broken by a random selection of a winner.

Although in any given auction the basic scenes are enacted over and over, these scenes are *articulated* in a systematic way: there are temporal and causal relationships between scenes which must be preserved for an auction to be performed and to be *legitimate*. The *buyers*, on the one hand, bid for the fish they want to buy, but they have to register as buyers previously and establish an adequate credit line which should be renewed when it is about to be exhausted (or completely exhausted). When a fish crate is bought, buyers should collect it, pay for it and take it with them. *Sellers* register their goods in the auction and collect the benefit when the goods are sold.

This articulation of scenes will be called the "Performative Structure" of an auction .Figure 3 is a schematic and simplified version of the Fishmarket, where each box corresponds to a scene whose diagram will be similar to the one for the bidding rounds.

Since in an institution each interaction is linked to an illocution (see section 1), these diagrams allow to describe simply all the admissible interactions in the auction house. It is clear that these schemata indicate the illocution sequences which are exchanged by agents participating in each scene, but they are not enough to determine what really happens when an illocution is made, or the

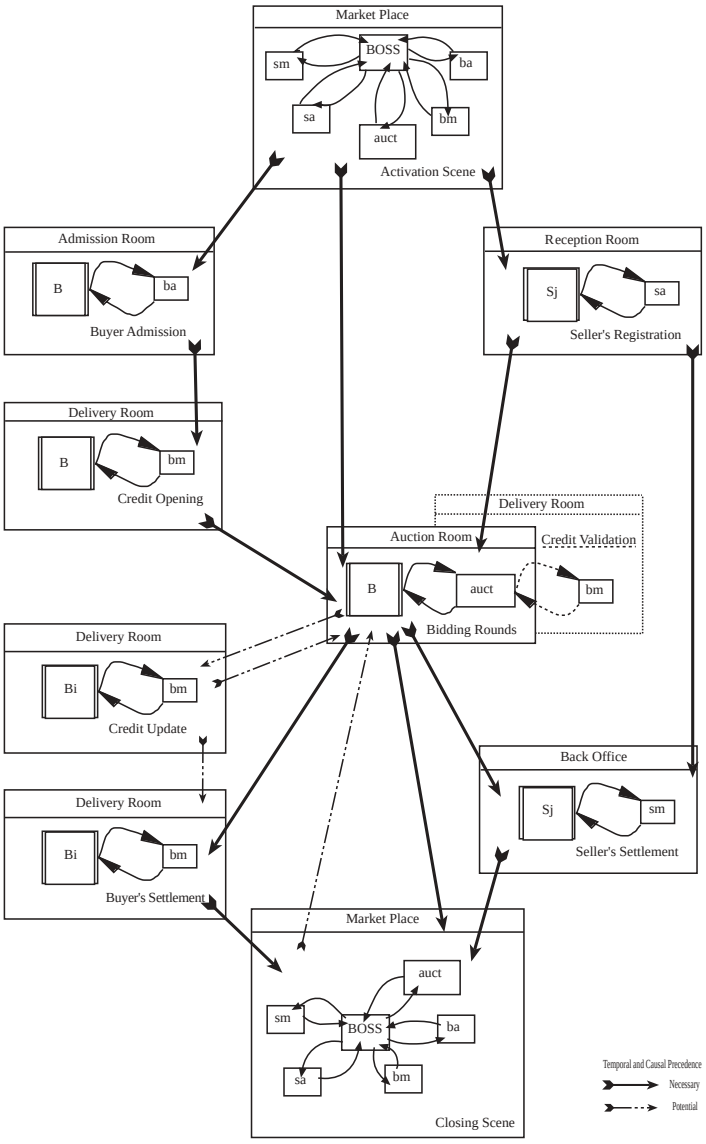


Figure 3: Superficial Performative Structure for the Fishmarket.

conditions which must prevail in the market for a certain illocution to be expressed by an agent. For this reason we require two additional elements: the market *commitments* and the *individual rules of behaviour*[5].

2.2 Commitments

In classical pragmatics terminology (e.g. Austin [1] or Searle [33]) illocutions "change the world" or "denote changes in the world" by establishing or modifying the *commitments* or *obligations* which are shared between participants.

The "world" for an auction house is anything which concerns auctions performed in that auction house[6]. Consequently, commitments established in an auction house are related to the exchange of auctioned goods, their features and the exchange conditions (that is, the registered good in the auction, who is its current owner, whether it has a reservation price, how much credit a certain buyer has, if he/she has to be fined, etc.) These commitments, whose satisfaction the institution is in charge of warranting, are established and modified exclusively through illocutions that *the institution considers acceptable* (because they attain to the institution's conventions) and thus we will call them "market commitments".

In the Fishmarket, as in most auction houses, market commitments are viewed as *terms* of a formal language —which can be interpreted as a database (distributed and with different views for each participant)— and can be specified around three main information structures: the auction's *catalogue* (which dynamically stores information related to the goods auctioned), *each seller's account* (which registers the most relevant aspects of that vendor, as its identification, the income and commissions applied) and *each buyer's account* (which includes data referring to his/her credit and the purchases made)[7].

The catalogue may be defined as follows:

Definition 1 (Auction Catalogue) *Be* $G = \{g_m\}_{m \in M}$ *a set of good identifiers,* T *a time model, and be* B *and* S*, respectively, the buyers and the vendors of an auction. Then,* CAT*, the* ***auction's catalogue*** *is the set* $CAT : G \times \widehat{G} \times S \times (B \cup \{\bot, \pm\}) \times \mathbb{R}^4 \times T^2 \times 2^{T \times INCI}$*, whose dimensions' meaning are defined on Table 2.*

Where:

- $\widehat{G} = \{\hat{g}_k\}_{k \in K}$ *is the set of types of good.*
- $\bot, \pm$ *denote that the good* was not sold *or was* withdrawn.
- $INCI$ *an* incident *list (collisions, ties, fines, expellings).*

Commitments referring to the catalogue are established, modified, and published according to the indications on Table 3. Other market commitments are described in a similar fashion.

[5] There are other notational conventions to express these diagrams' content: coloured Petri nets, Script languages, π-calculus, etc. Some of them may denote, in the very formalism, the protocol and some market commitments, as well as conventions regarding individuals.

[6] It is the "Dialogical Framework" (Cf. Secc. 3.1).

[7] There are other complementary structures with an operative or implementational character (collision count, virtual space occupants, etc.).

$CAT_1 =$	$g \in G$	(the *catalogue number* of g)
$CAT_2 =$	$\hat{g} \in \widehat{G}$	(the *good type* of g)
$CAT_3 =$	$seller(g) \in S$	(the *seller* of g)
$CAT_4 =$	$buyer(g) \in B \cup \{\perp, \pm\}$	(the buyer of g, if it exists)
$CAT_5 =$	$p_{rsv}(g) \in I\!R$	(*reservation price* of g)
$CAT_6 =$	$p_0(g) \in I\!R$	(*initial* price for g)
$CAT_7 =$	$p_t(g) \in I\!R$	(price in t time)
$CAT_8 =$	$p_\omega(g) \in I\!R$	(*final price*)
$CAT_9 =$	$t_0(g) \in T$	(*registering* time)
$CAT_{10} =$	$t_\omega(g) \in T$	(*sale* time)
$CAT_{11} =$	$incdt_t(g) = \{\langle t,i\rangle : t \in T \wedge i \in INCI\}$	(incidents with g)

Table 2: the Fishmarket catalogue

CAT_i	Content	Definer	When	Known	When	Known by all
CAT_1	g (id)	**sa**	newlot	All	present(lot)	-
CAT_2	$\hat{g}$ (type)	**s,sa**	register	**auct**	newlot	present(lot)
CAT_3	$seller(g)$	**s,sa**	register	**auct**	newlot	present(lot)
CAT_4	$buyer(g)$	**auct**	cr-val/ re-dec.	**bm**	credit-val.	adj./w,
CAT_5	$p_{rsv}(g)$	**s,sa**	register	**auct**	newlot	withdrawn
CAT_6	$p_0(g)$	**s,sa**	register	**auct**	newlot	new-good
CAT_7	$p_t(g)$	**auct**	newgood/rebid	All	offer	-
CAT_8	$p_\omega(g)$	**auct**	cr-val/ re-dec.	**bm**	credit-val.	adj./w.
CAT_9	$t_0(g)$	**sa**	register	**auct**	newlot	present(lot)
CAT_{10}	$t_\omega(g)$	**auct**	cr-val/ re-dec.	**bm**	credit-val.	adj./w.
CAT_{11}	$incdt(g)$	**auct**	coll/cr.val	All	tie/rebid	-

Table 3: Market Information about Goods in the Fishmarket

2.3 Individual Behaviour Rules

This way of describing social conventions, however, is not very explicit. If one wishes to make sure that all agents taking part in an auction follow "the rules of the game", it would be convenient to state these rules in a way that is easy to communicate to external agents and its observance easy to check (by internal agents, or by some other external agent). One could then unambiguously define, for each illocution, its *generation* and *interpretation* conditions. That is, which are the *conditions which must prevail* in the market commitments for the participant which utters them, and which are the *effects* that such illocution should have on the market commitments of those participants hearing it.

For instance, for an auctioneer (**auct**) to offer a good, such good should be the first unsold good in the catalogue. And if a buyer accepts an offer, the buyer manager (**bm**) is *required* to change that buyer's account, to fine him/her if he/she is insolvent or to expel him/her; if the good is assigned, the institution will cease to have this good in store and will be *compelled* to deliver it to the buyer, and to reflect in the catalogue the state of the good, it's final price and it's buyer.

Let us look for instance at four rules (Table 4) which specify the auctioneer and buyer manager's expected behaviour in the assignment of a good and the choice of the next good in the catalogue (that is, from state S12 and to the states S17 and S5 in Figure 2).

The process is the following: when the buyers' manager (**bm**) declares a valid buyer's (**b**) credit (i.e. the potential buyer is solvent), the auctioneer (**auct**)

will update the information corresponding to such good in the catalogue as well as the unsold goods list and his/her own unsettled tasks before declaring the good assigned. This reasoning is represented by Rule 1.

When the good is assigned, the auctioneer will attempt to auction another good. If there are still unsold goods, it will choose the first on the list, but before offering it (with the appropriate initial value) the auctioneer will have to update its commitments (Rule 2).

If the auctioneer has got no more goods to sell, it must ask the sellers' admitter (**sa**) for a new lot to auction (Rule 3)[8].

Rule 1 *(**adjudicate**$_{\mathbf{auct}}$)*

IF	$assert(bm, auct : valid(b), t)$
$THEN$	$credit_{t_{now}}(b) := credit_t(b) - p_t(g)$
AND	$buyer(g) := b$
AND	$bundle(b) := bundle(b) \cup \{g\}$
AND	$t_\omega(g) := t$
AND	$SG := APPEND(SG; g)$
AND	$UG := REST(UG)$
AND	$Pend_{auct} := UG)$
AND	$declare(auct, all :$ $sold(g, buyer(g), p_\omega(g), t_\omega(g)); t_{now})$

Rule 2 *(**newgood**$_{\mathbf{auct}}$)*

IF	$declare(auct, all :$ $sold(g, buyer(g), p_\omega(g), t_\omega(g)); t)$
AND	$UG \neq \emptyset$
$THEN$	$g := FIRST(UG)$
AND	$p(g) := p_0(g)$
AND	$WAIT(t_{now} \geq t + \Delta_{rounds})$
AND	$offer(auct, all : tosell(g, p(g)); t_{now})$

Rule 3 *(**newgood**$'_{\mathbf{auct}}$)*

IF	$declare(auct, all :$ $sold(g, buyer(g), p_\omega(g), t_\omega(g)); t)$
AND	$UG = \emptyset$
$THEN$	$request(auct, sa : moregoods; t_{now})$

Rule 4 *(**adjudicate**$_{\mathbf{bm}}$)*

IF	$declare(auct, all :$ $sold(g, buyer(g), p_\omega(g)); t)$
$THEN$	$ahincome := ahincome+$ $(\Pi_{spremium} \times p_\omega(g))$
AND	$BA(b) := APPEND(BA(b);$ $\langle t; purchase : b, g, p_\omega(g); credit(b)\rangle)$

Table 4: Adjudication rules in the Fishmarket

Meanwhile (Rule 4), when the buyers' manager (**bm**) is informed of a good being assigned, he/she proceeds to updating the market income (*ahincome*) and the corresponding buyer's account ($BA(b)$)[9]. The sellers' manager (**sm**) reacts analogously by changing the seller's account and charging the corresponding commission.

In general, rules are stated for each participant type, in each scene and for each illocution that the type of participant can utter or receive; as it was seen in the previous case, there can be more than one rule for each illocution. This enumeration of rules is based on two methodological reasons: The first, which we have already mentioned, is due to the need of making these conventions explicit and more intelligible for users or external observers. The second is to

[8] These Fishmarket rules use terms such as: SG y UG (sold and unsold goods list, respectively), $Pend_{auct}$ (auctioneer's pending tasks), $bundle(b)$ (the "shopping basket" for b), Δ_{rounds} (the waiting time between rounds), etc. It can also include instructions such as $WAIT$ and $REST$ which refer to the computational realization of the corresponding operations.

[9] Whose credit ($credit(b)$) reflects the cost of the purchase, since the credit manager should have changed it before declaring the bid valid.

facilitate the definition and update of the institution's conventions. This second methodological reason is expanded on in the section below.

2.4 Covention variants

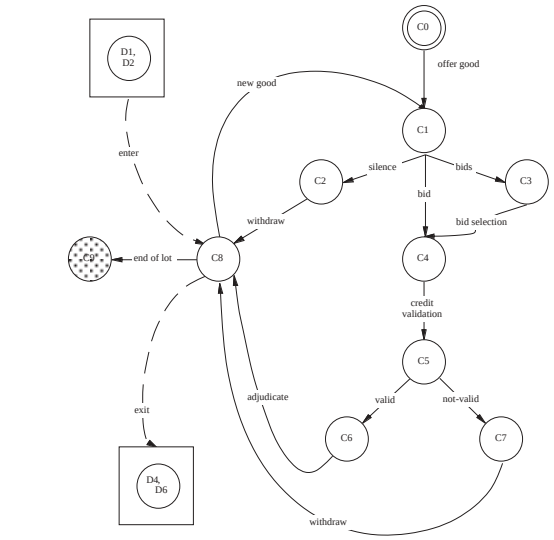
It should be evident that the individual behaviour rules must correspond with the scene protocols. However, such correspondance is not always easy to achieve. The art is in the choice and analysis of illocutions and it's interrelation with the diagrams. To illustrate this point let us look at a very important variant of the Fishmarket: *closed bid* auctions. In this convention there is a single bidding round where the ones to bid submit their offers which are known to the rest of the bidders (hence the name) and the highest bid wins. Figures 4 represents the closed bid protocol (CBP) which here includes a few additional illocutions to deal with offer validation and the limiting case when no bids are received[10]. It should be no surprise that the illocutions on this diagram are almost identical to the ones on Table 1, with the exception that in the Fishmarket the buyer only *accepts* the auctioneer's offers including a price, whereas here, it is the bidder whom proposes the price he/she is ready to pay in the bid[11]. The credit validation request is also slightly more complex since the auctioneer communicates the credit manager a (sorted) list of bids which satisfy the auction house's requirements, so that either the highest valid one be returned, or none in case there is not. These considerations produce the following illocutions:

$$
\begin{array}{l}
offer(auct, all : tosell(g)) \\
assert(b, auct : bid(b,p)) \\
declare(auct, bm : selected(\{bid(b_i, p_i)\})) \\
request(auct, bm : creditstatus(\{bid(b_i, j)\})) \\
assert(bm, auct : valid(b,p)) \\
declare(auct, all \cup \{bm\} : sold(g, b, p, t_\omega)) \\
assert(bm, auct : invalid) \\
declare(auct, all \cup \{sm\} : withdrawn(g, t_\omega)) \\
declare(auct, all : endoflot)
\end{array}
$$

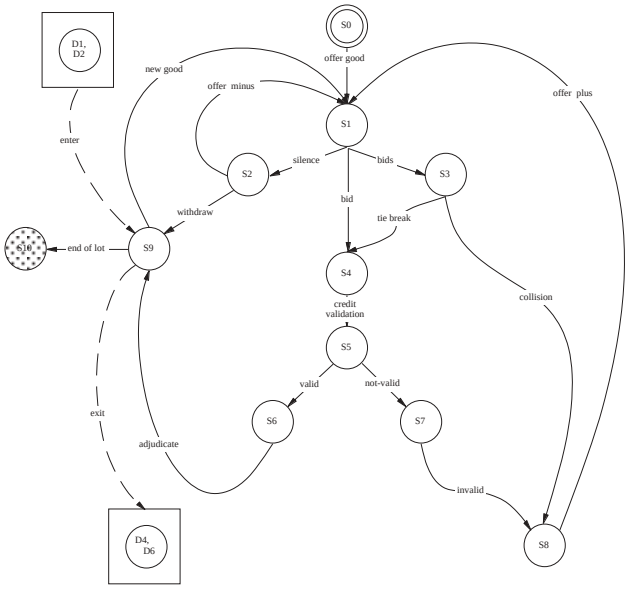
From these illocutions some individual rules should be stated for all participants. This is a trivial task since market commitments can be represented by the same information structures from Fishmarket even though a new *selected* operator should be added and the *creditstatus* extended so as to be able to cope with the new offer selection processes (in the Fishmarket the only offer received was selected or a tie was broken selecting randomly one of the bids).

Let us suppose that we have finished this tedious process and we have the new upward-bidding protocol and its corresponding rules, conveniently debugged and correctly described. Then, we can *immediately* generate a new Fishmarket variant: *Vickrey* bidding ([43]). This is also a closed bidding process, in which the winner is also the highest bidder, but he/she pays only the amount of the second highest bid. In order to represent this new bidding convention, assuming the previously represented closed bid convention, one then only need to change the *selected* operator (and the corresponding auctioneer rule); the rest remains

[10] A correction suggested by simple comparison with the Fishmarket bidding protocol.
[11] Additionally, we do not take expellings and fines into account.

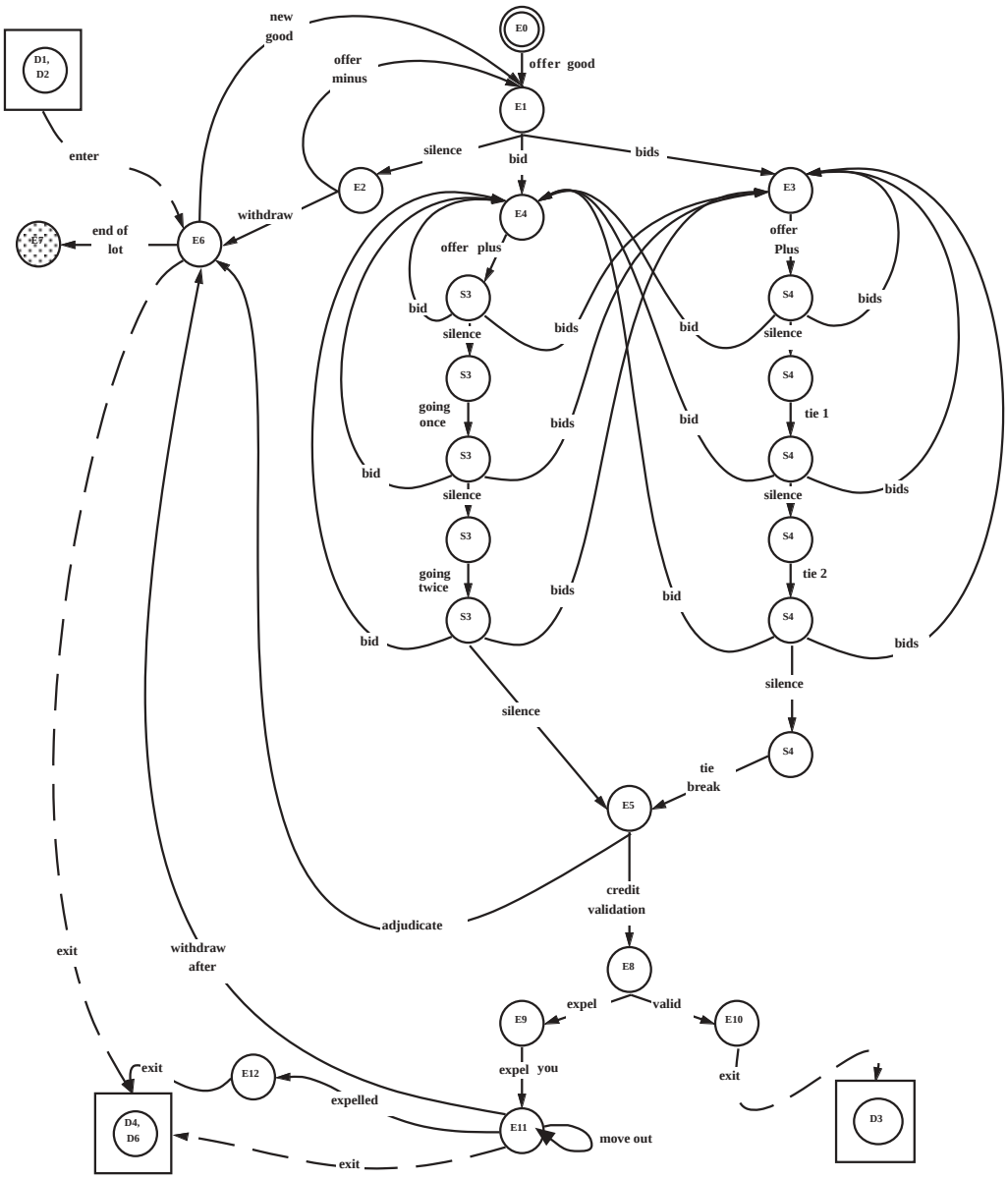


Sealed bid/ Vickrey



Downwards bidding

Figure 4: Classic Diagrams for two Bidding Protocols.



Upwards bidding

Figure 5: Classic Diagram for the Upwards Bidding Protocol.

the same[12]. The *selected* operator is the key in this flexibility. In fact, most of the upward-bidding conventions in *public procurement* are variants of the *closed bid* biddings, and can be represented through simple modifications in the selection operator which can be defined in general as a function associating the bidder to the amount it should pay if the good was assigned to him/her. That is why *parametrizing* it would be convenient, in such a way that the same protocol, the same individual rules, the same illocutions and the same operators could be used for any of its variants, and it were only necessary to make these operator's parameters explicit to use it in a given licitation convention.

Let us now compare, without entering details, the upward-bidding Fishmarket diagram with the *upward-bidding* (or "*English*" bidding, bottom of Figure 5). It is clear that the resemblances are less evident here than in the centre of the diagrams, inspite of superficial similarities. But considering the complete Fishmarket Performative structure and substituted in the bidding rounds scene, the current bidding protocol for the *upward-bidding* protocol, we would almost immediately obtain an auction house very similar to Sotheby's.

The steps from the *closed bid* auction to *Vickrey* and to a generic conventions of the *public procurement* became trivial. In fact, the step from the Fishmarket bidding to the closed envelope was simple since we aimed at changing only the upward-bidding protocol and two operators. Fishmarket's transformation for *upward-biding* is not so easy, but its description and depuration would follow processes very similar to the ones followed by the first transformations, since the elements that must undergo modification can be directly made explicit. It would be worthwhile obtaining a way of characterizing those elements of an *auction convention* which could be **systematically varied** and produce alternative conventions —without requiring substantial modification s either in the operators, in the rules or in the protocols.

Having so much simple diagrams and the corresponding rules sets in a relatively simple notation to represent interactions, allows for the description these potential variants in a reasonably simple way. It is in commitments, and the way in which the operators which manipulate them work, where practical difficulties lie. These difficulties can be greatly avoided through the use of sufficiently general operators (which, when parametrized, are equally useful for the different variants) and the information structures which are appropriate for these forseeable operator variations.

The truly difficult problem to face is that rules and protocols must be *executable*. That is, if an auction house adopted them and buyers and sellers met at auction houses to exchange a set of goods, then exchange must adhere to these conventions (if enough resources and interest existed). For this reason it is necessary to show that a given description based on diagrams, information structures and rules are correct. That is, coherent in the handling of commitments and *feasible in pragmatic terms*. To discuss this difficulties, we will try to formalize some aspects of the Fishmarket.

[12] In the definition of *selected* the only offer case must have been solved, whereas in the case of zero offer reception, this had to be resolved in the definition of *creditstatus* —since it was introduced for the *closed envelope* convention.

3 Towards a Formal Model

At the beginning of this chapter we stated that in order to characterize a virtual institution three types of convention were necessary: The ontologic, social, and the individual behavioural conventions. We have devoted most of the chapter to the later two. We shall now concentrate on the ontologic conventions so as to approach some formal elements of the other conventions.

3.1 Dialogical Framework

In previous examples goods, participants, roles and locations, instants and time intervals, incidents, actions, prices and many other elements were parts of illocutions, rules and commitments. To establish (either operationally or formally) the individual and social conventions which constitute the Fishmarket *deontology* (or of any other auction) we need a rich *ontology* and have the appropriate communication and specification languages for these norms. A common reference framework for all participants in an auction is required which will enable them to communicate (and understand each other) inside the auction house. Since we have decided to understand some virtual institutions as multiagent systems in which all participants interact *dialoguing* —through an illocution exchange— we will call this common reference framework for all participants *Dialogical Framework*.

The components of such *Dialogical Framework* for the Fishmarket, $\mathcal{DF}_{FM}$, are the following:

1. $\mathbf{Agents}_{FM}$ a set of identifiers (which could be used to denote specific agents),
2. $\mathbf{Rol}_{FM} = \{\mathbf{boss}, \mathbf{auct}, \mathbf{sa}, \mathbf{sm}, \mathbf{ba}, \mathbf{bm}\} \cup \{\mathbf{s}, \mathbf{b}\}$ (the agent types taking part in a Fishmarket auction)
3. $\mathcal{SR}_{FM} = \{\langle \mathbf{boss}, x\rangle : x \in \mathbf{Rol}_{FM} \setminus \mathbf{boss}\}$ (Authority relationships in the Fishmarket: the *market boss* has authority over all participants in an auction)
4. $\mathbf{Loc}_{FM} = \{AH, RR, AR, DR, BO, M\}$ (the virtual locations)
5. $\mathcal{L}_{FM}$ the "object language" $\{\Delta_{bid}, \Pi_{spremium}, \ldots, CAT, \ldots bid, tosell, endoflot, credit, ahincome, \ldots\}$)
6. $\mathcal{CL}_{FM}$ (a communication language, with formulae of type $\iota(\alpha, \Gamma : \varphi; \tau)$, with $\alpha \in \mathbf{Rol}_{FM}$, $\Gamma \subseteq \mathbf{Rol}_{FM}$, $\varphi \in \mathcal{L}_{FM}$ and $\iota \in \mathcal{I}_{FM} = \{assert, request, deny, accept, declare, command\}$),
7. $\mathcal{ML}_{FM}$ the corresponding metalanguage to define behaviour rules (including other languages).
8. T a time model (e.g. discrete, acyclic and forward branching).

Adopting a nominalist attitude, we may assert that the Fishmarket is formed by all the *entities* which we have to refer to inorder to establish the "rules

of the game" of that auction house. Recall that such game rules were described by the "Performative Structure" —formed by scenes, their protocols and commitments— and the "individual rules of behaviour" to which each participant is subject when taking part in a scene. We will now introduce some more elements for the purpose of referential clarity.

3.2 Fishmarket's Deontology

We have seen before that there are six virtual locations in the Fishmarket (**AH**,**RR**,**AR**,**DR**,**BO**,**M**) and that there is always a staff member who is in charge of supervising the scenes taking place there (**auct**,**sa**,**ba**,**bm**,**sm** and **boss**, respectively). In some virtual spaces more than one scene may be performed (for instance, in **DR** credits are opened, closed and updated and in **M** the market is activated and closed).

We have also seen that in each scene there is a protocol in which all the permissible illocutions for those scenes by the participants are indicated according to their roles. We also mentioned that certain structures keep each other a (temporal and causal) precedential structure. Given these elements we define the "Performative Structure" ($\mathcal{PS}_{FM}$) of the Fishmarket as:

- The scene sets: $\Sigma_{FM} = \delta_0, \ldots \delta_8$ whose interdependence is given in Figure 3, and in which an interaction diagram with its corresponding illocutions corresponds to each box (as the one in Figure 2 —with Table 1— corresponds to scene D_4 of auction Rounds).

For each participant and each scene we associate to each illocution in that scene the individual behaviour rules which may affect that participant in the given scene (either the producer or receiver of that utterance).

That is, if ρ is a role in $\mathbf{Rol}_{FM}$ and δ a scene in Σ_{FM}, then $BR(\rho, \delta)$ will be the individual behaviour rules of the participant performing a ρ role in the scenes δ. $BR(\rho, \delta)$ is formed in the following way:

- For all illocutions $\iota(\alpha, \Gamma : \varphi; \tau)$ of the scene δ such that $\rho \in \{\alpha\} \cup \Gamma$, at least one rule R exists such that:
  - If $\rho = \alpha$, then $\iota(\alpha, \Gamma : \varphi; \tau)$ is in the antecedent of R, and
  - If $\rho \in \Gamma$, then $\iota(\alpha, \Gamma : \varphi; \tau)$ is in the consequent of R

¿From these role and scene rules we may define the Fishmarket individual behaviour rules as $\mathcal{BR}_{FM} = \{BR(\rho, \delta) : \rho \in \mathbf{Rol}_{FM}, \delta \in \Sigma_{FM}\}$.

With the *dialogical framework*, the *performative structure* and the *individual behaviour rules* we define an *institution*. In fact, we have already "formalized" an *auction house* $\mathcal{FM}$ which corresponds to the Fishmarket:

$$\mathcal{FM} = \langle \mathcal{DF}_{FM}, \mathcal{PS}_{FM}, \mathcal{BR}_{FM} \rangle$$

3.3 Models and Implementation

In order to formalize this Dialogical framework and interprete the Performative structure of the Fishmarket and it's behaviour rules, we must rely on a given semantics and pragmatics.

The semantics may be relatively standard (using the obvious intuitions of the meanings of the elements in the dialogical framework and translating them to a formal structure which interprets them in terms of market commitments). The pragmatics has to account for how an institution permit an auction which respect it's conventions.

Let us suppose that A is an auction, characterized by the auctioned goods $\mathcal{G}$, the participating agents $\mathcal{A}$ and the status of the market along time (that is, a finite sequence of states which indicate how the goods possesion, the resources, the incidents evolve, since the situation before the auction, $\mathcal{E}_0$, until the auction finishes $\mathcal{E}_\omega$. And be $\mathcal{FM}$ an auction house.

We want to build an $\mathcal{FM}$ *institution* which allows for the *performance* of the auction A, in such a way that one can go from $\mathcal{E}_0$ to $\mathcal{E}_\omega$ through a dialogical process in which involves the agents faithfully following the $\mathcal{FM}$ conventions.

Notion 1 *An auction* $A = \langle \mathcal{A}, \mathcal{G}, \langle \mathcal{E}_0 \ldots \mathcal{E}_\omega \rangle \rangle$ *is* ***performed*** *in an auction house* $\mathcal{FM}$*,*

$$\mathcal{FM} \models A,$$

if $\mathcal{E}_0$ *becomes* $\mathcal{E}_\omega$ *through a dialogical process involving* $\mathcal{A}$ *and* $\mathcal{G}$ *which satisfy the auction conventions of the* $\mathcal{FM}$ *institution.*

There are various options to formalize $\mathcal{FM}$. One of them consists in adopting a convention similar to Model Theory (e.g VanLinder and Dignum [7] or Dialogical extensions to Singh [36] or Vandervecken's [34] proposals). Another possibility is formal specification; for instance, one based in Dynamic Logics (as the one proposed in our articles [20] and [19, Ch. 10]) or closer to implementation, one based in π-calculus ([23]). But one may also directly use a *computational realization as a multiagent system*, as our virtual lodge FM96.5 ([27]).

While the first options have an analytic and formal interest (which, amongst other things, may provide with formal predictive results), the last has normative and evidently practical advantages.

Space does not allow us to enter into details, but we must mention that in FM96.5, the abstract version of the Fishmarket that we have discussed here is reproduced with remarkable faithfulness and a fair, lively and reliable more than reasonable for the performance of on-line auctions through a "reliable" web[13].

The interest of this development does not only lie on its virtual institution character. From the methodological point of view, it also provides some teachings. The most obvious are the advantages of dialogically describing the auction house (with the consequent economy in the definition of the agents, their interactions and ostensible behaviour), the anthropomorphizing of the intermediate agents (and consequently the ease to produce variants and adaptations from the original model) and to be able to achieve, from the performance (but not only formal) point of view, that human and external agents become *indistinguishable* [14]. In fact, FM96.5 has now an additional layer of computational developments

[13] That is, a Web (such as the internet) in which it is guaranteed that messages are not lost and that their broadcasting sequence is preserved (even though neither homogeneous answer times or synchronization are guaranteed).

[14] Which is achieved through a careful analysis of the implementational aspects of the protocols of the scenes and the invention of *institutor* devices which restrict the behaviour of external agents to the institution conventions strictly.

which make it an auditable auction house, as well as making it a most flexible and robust testing ground for variants of the Fishmarket (FM97.6) (see [28]).

4 Institutions

The notion of virtual institution we have presented here to describe and formalize the Fishmarket is very general. In a similar way to the one used for the Fishmarket it is possible to describe the scenes and behaviour rules of other multiagent systems in which the interactions must adhere to a more or less precise protocol; and from there, building its computational version.

For instance, in order to reproduce an auction house as Sotheby's, in which the main differences lie on the upward-bidding conventions, changing the upward-bidding and downward-bidding diagrams in Figures 5 and 4 in the corresponding part of Figure 2 (and varying the corresponding individual rules) would be sufficient, but the surface performative structure and the rest of the scenes would be unaltered. In the same line, generalizing $\mathcal{FM} = \langle \mathcal{DF}_{FM}, \mathcal{PS}_{FM}, \mathcal{BR}_{FM} \rangle$ for an auction house generally means only pointing out which fragments of each of these three components are preserved and made explicit in the change of diagrams and rules.

In addition to auctions, it is also possible to define in similar terms less structured interaction convention types. For instance, the open negotiation described in [35] may reflect a dialogical framework simpler than the Fishmarket (since it includes only a scene and no mediating agents) but whose language is more elaborate (in L (*Deals*) are mentioned, in CL requests, offers, threats and other arguments, and ML includes elements as the one denoting each agent's preferences, reification functions, etc). In the case of the argumentative negotiation, the performative structure includes only a scene which diagram joins the Open Negotiation Protocol and the individual rules corresponding to the rules which make this interaction sequence clear and the minimum common components for the generation and interpretation of illocutions.

In all these cases, an *agent-mediated institution* is defined as a collection of participating agents (in principle software agents) in which the theoretical components are specified around the three mentioned structures: dialogical framework, performative structure and individual behaviour rules. The implementation of such a multiagent system corresponding to these institutions may be achieved the same way as FM96.5 and FM97.6. Indeed, current developments allow the implementation of simple variants of the Fishmarket (as the Vickrey auctions and the public licitations).

Following the same methodological criteria used in the development of FM96.5, more robust flexible and checkable multiagent systems may be built, as FM97.6.

With such an approach, we have adopted the formalization of the "Cohabited Mixed Reality Information Spaces" project; real-virtual spaces where human agents use automatic personal assistants to perform some joint actions, such as arranging meetings during a fair [24]. In this project we use the notion of *agent-mediated institution* to represent not an auction house or a market, but a fair or congress space and characterize the typical scenes in these events in which a person may benefit from the help of a computerised personal assistant to explore that space, identify interesting action opportunities and even coordinate some of them. Again, the dialogic approach makes not only the

identification and implementation of interaction protocols' formal framework mentioned above easier, but also the implementation of the *institutional environment*, the multiagent system and the specific agents, which allow performing a virtual institution.

Also as part of the SMASH project (<http://www.iiia.csic.es/Projects/smash>) we have started using the idea of *Agent-Based Institutions* to represent the "medical protocols" of care and attenti on towards patients. The aim of that project is to endow the different participants in a hospital (patients, physicians, nurses, managers) with artificial assistants which allow them to follow the steps of a "medical protocol" and identify omission of expected protocol steps, take note of changes, give notice to the one in charge, adjust the protocol or carry out corrective measures. For this reason, the institutions on roles, scenes, protocol and rules mentioned around the Fishmarket are used again.

5 Closing remarks

This research and development exercise may be justified on three different grounds: from the point of view of general Artificial Intelligence, from the most specific of multiagent systems, and from the approach of optics related to electronic commerce.

1. **For Artificial Intelligence** at least two considerations can be pointed out which are relevant. On the one hand, the analysis and modelling of a particular auction house, and of institutions based on agents in general is a interdisciplinary problem. Distributed computation, pragmatic linguistics, mathematical economy, negotiation and metaphysics are only but a few problems which Artificial Intelligence may provide relevant methodological and technical solution.(cf. e.g., [13, 33, 36, 11, 6]).

The other consideration is during auction modelling, where three identification lines which are fundamental to this modelling were identified, and may be of interest to other fields of AI: the *Situated Reasoning* characteristic of Dialogic Systems ([26, 9, 44, 18]) or Computational Dialectics ([41, 25, 12]); the *Agent-Based Institution Design*; and the *reliability* condition to which all interactions in a virtual institution are subject to.

2. **As multiagent Systems**, the agent-mediated auctions in which software agents may take part, or software agents such as buyers and sellers may perform a function, have a special appeal for at least the following reasons:

a). They constitute a *non-trivial problem*. The challenge is that the information present in an auction is not only abundant and contains a great uncertainty, but also constantly changing and, in the typical auctions (such as the Fishmarket), it changes very quickly. For this reason the development of agents which can successfully develop in such an environment is very difficult, and requires making use of a great amount of proposals and developments on automated reasoning.

b). They are, on the other hand, a domain in which *competitive evaluation* is possible: one which is objective and direct in the development of participants (and of the own institutions) due to the very competitive nature of an auction. This is an element which is used to build test platforms such as FM97.6, which can be applied to the evaluation of auctions and a very wide number of agent-based institutions.

c). The most significant reason is that auctions are a *conveniently scalable* problem inside a general program of investigation in multiagent systems. Such scalability is possible due to the fact that the *social* features, which are present in this form of coordination, are very simple and alien to the *individual* factors implicit in decisional processes. That is why it is possible to easily separate both factors and using auctions as a testing ground for the development or experimentation of architectures, heuristics, and strategies which, when applied to agents taking part in an auction, may also be relevant for other means of coordination (as the crossing of intentions in a stock market or open negotiation and bargaining).

3. Finally, from the perspective of **Electronic Commerce**, we must point out three additional aspects:

a). Electronic exchanges through the Internet (cf.[40, 16, 22]), and particularly the sudden success of on-line auctions, has considerable potential and relevance. This trend emphasises a need for scientific and technologic considerations for opportunities in developing trading institutions for automated negotiation or mediation through software agents.

b). The opportunity of developing agents which take part such institutions. Solving the difficulties (either ergonomic, rule-related, operative or ability-related) with an intensive and generalised use in commerce will result in patents.

c). Finally, the interest derived from the development (and design) of *new commerce practices* as a result of the aforementioned mentioned developments. But, in addition to that, the need of instituting *other practices* (and the consequent technological instruments) which are reliable, checkable and possibly subject to some kind of certification and independent audit. Such practices and technologies must build a *reliable*, *safe* and *profitable* electronic commerce.

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