Carrel: An Agent Mediated Institution for the distribution of Human Tissues

U. Cortés[1], A. López-Navidad[2], J. Vázquez-Salceda[1], A. Vázquez[1], S. Lopes[1], D. Busquets[3], M. Nicolás[1], F. Vázquez[1], and F. Caballero[2]

[1]Departament de Llenguatges i Sistemes Informàtics.
Universitat Politècnica de Catalunya.
c/ Jordi Girona 1-3. E08034 Barcelona, Spain.
{ia, jvazquez, avazquez, eslopes, mnicolas, fvazquez}@lsi.upc.es
Phone: 34 934017016 Fax: 34 934017014
[2]Banc de Teixits. Hospital de la Santa Creu i Sant Pau
c/ St. Antoni M. Claret, 167. E08025 Barcelona, Spain.
alopeznavidad@hsp.santpau.es
Phone 34 932919335 Fax 34 932919410
[3]Institut d'Investigació en Intel.ligència Artificial,
Consejo Superior de Investigaciones Científicas
Campus UAB, 08193 Bellaterra, Barcelona, Spain
didac@iiia.csic.es
Phone 34 935809570 Fax 34 935809661

Abstract. In this work we present an application of Intelligent Agent Technology to create an institution which mediates in the distribution of Human Tissues for transplantation. The creation of an Institution, called *Carrel*[1], will aid in finding intelligent means for a better assignation of organs, tissues and bones banked for transplantation in human, an activity whose importance in health care is growing and also is very important in economic terms. *Carrel* follows the approach of other well-known Agent Mediated Institutions such as Fishmarket [4], [8] and AuctionBot [17], [15] in order to assure fair distribution of resources.

Keywords: Autonomous Agents, Real-Time Systems, Multi-Agent Systems, Agent Mediated Institutions, Negotiation.

1 Introduction

Nowadays organ and tissue transplants have an increasing importance for health, as a single organ donor can satisfy the transplant needs of dozens of organ and tissue recipients [6], For many of them transplantation represents the only therapeutic alternative and even their only chance for survival. It is also very important in economic terms. For instance let us take the case of Spain, where transplantation of one kidney compared with dialysis would save the patient or the social security services between 186400 and 240530 Euros.

Spain has become the first transplant organization in the World with 33 cadaveric organ donors per million population (pmp) in 1999 (37 donors pmp in Catalonia), and that some years ago lead to the creation and implantation of several *Tissue Banks* (TB), institutions specialized in the extraction and maintenance of tissues and bones from cadaveric donors for its subsequent use in transplantation.

An altruistic way to distribute those organs and tissues is needed. Our proposal is to build an Agent Mediated Institution to regulate and speed the assignation of tissues and bones. The main objectives of this Institution[2] are: (1) to guarantee a fair and equitable distribution of tissues and bones, (2) to optimize the exploitation of the Tissue Bank and, (3) to improve the knowledge and methodologies associated with Transplants, for example in determin-

[1] Upon Alexis Carrel [1873-1944], who received the 1912 Nobel Prize. He laid the groundwork for further studies of transplantation of blood vessels and organs.

[2] Here we follow North's definition of an *Institution* as a collection of artificial constraints that shape human interaction [9].

ing the relationship between donor tissue and recipient characteristics that influence graft survival. *Carrel* is, in a sense, an Intelligent Resources Management Service.

Carrel is designed to share among the Hospitals that are members, all the information stored in the different Banks of Tissues and to assign the *best* piece to the recipient that shows the *best* match with the available pieces. The coordination among TBs could be done at regional level (eg. in Catalonia), national level (eg. in Spain) or transnational (eg. in the European Union) taking profit from a single negotiation protocol, the information standardization and using the communication facilities provided by Internet. Of course, the exchange of tissues has to observe the local, national and European Union legislation (see the reports of the ONT in [2] and the recommendations of the Transplant Experts Committee in [7]).

1.1 Organization of this paper

This article is organized as follows. First, in section 2 we will briefly describe *Carrel*, the explanation of the *Carrel*'s scenarios is made in §3 and the main norms enforcing negotiation are detailed in §4 and in section §4.1 we explain the characteristics of the kind of interactions that can take place inside *Carrel*. In section §5 we describe our proposal for data standardization in this field. Finally, in §6 we give some conclusions and explain the future lines of research.

2 Carrel: An Agent Mediated Institution

Carrel is an Agent Mediated Institution designed to allow the distribution of human organs, tissues and/or bones[3] for transplantation. It is an Intelligent Resources Management Service. The central idea is to bring all the information from the different TBs into *Carrel*, so Agents representing different Hospitals can access the Institution and negotiate for the pieces the Hospital needs for a given transplantation. Those Agents have to accept *Carrel*'s norms of negotiation (see §4). This fact determines the co-operative nature of the Institution. In figure 1 we show the *Carrel*'s global view.

[3] From now on we will use the word *pieces* to designate organs or tissues or bones.

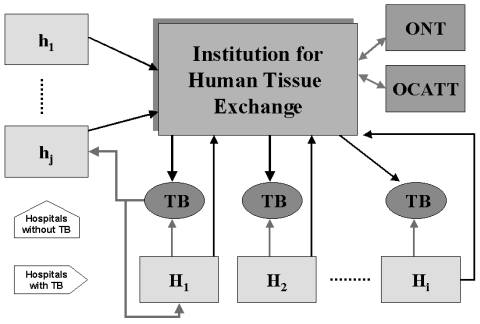

Fig. 1. Carrel: An Agent Mediated Institution for Tissues Assignment

From the point of view of multiagent interactions, organs and tissues exchanging is a very attractive issue. These transactions are the kind of situations where one can claim that agents are well suited as they require: reactivity, situatedness, social abilities and autonomy [16],[14].

Organs and tissues exchanging could be classified as Task Oriented Domain (TOD). In those domains agents's activity can be defined in terms of a set of tasks that it has to achieve [11].

Agents inside *Carrel* have to represent a hospital that needs a single piece for transplantation (eg. a cornea or a heart valve) and they have to present this petition to the Institution. This petition will be formulated as a sealed envelope. If there is a set of available pieces, those will be presented, following the Institution's norms (see §4), to the Agent to choose in terms of its internal *selection function* (see [1]). This function varies according to (1)the kind of organ, tissue and/or bone, and (2) the surgeon or hospital transplant criteria.

Let us now identify the actors of *Carrel*: although we are talking for the general case most details correspond to the Catalan case. The most important actors are the Tissue Banks, as they provide the pieces for transplantation, the Hospitals, the National Transplantation Organization[4] (ONT) [10] and the Organització Catalana de Transplantaments (OCATT). The precise role of OCATT and ONT for the Catalan case is described in [5].

[4] The Organización Nacional de Transplantes is a technical organization within the Spanish Department of Health and Consumer Affairs, without attributes of direct management and whose fundamental mission is the promotion, facilitation and coordination of all types of organs, tissues and bone marrow.

The participation of hospitals in *Carrel* is based on the notion of membership. That is, hospitals adhere to the Institution and respect the negotiation (assignation) rules and the agents that represent them inside *Carrel* are unable to break these conventions. Each Hospital has a Transplant Coordination Unit Agency called *UCTx* that allows to interact with the Institution (see §3.1 in this work for more information about hospitals, see [1] for a deeper explanation of the UCTx Agency).

The *Tissue Bank* (see §5) keeps information of all available pieces and participates in the negotiation process in three different ways: a) providing *Carrel* with ALL the information it has about all available pieces, b) delivering the pieces assigned by the Institution and, c) tracking of the transplanted pieces. In most of the cases, as shown in figure 1, the hospital does not take care of the Tissue Bank as most hospitals do not have a TB.

The Agents that come into *Carrel* represent each Hospital. The negotiation for a piece in *Carrel* takes place in the Exchange Room (see figure 2). There Agents deliver a sealed envelope with all the required information: the hospital's identification (provided by the Institution), the desired piece identification, recipient relevant information, hospital transplant coordinator's electronic signature, and it also contains the Selection Function which is private information. In *Carrel*, the OCATT and ONT do participate and their role is as observers of the whole process and maybe the ultimate referees in the case of conflicts.

In the next sections we will go into more detail in each of the components of *Carrel*.

3 Institution

The Institution is responsible of assuring the soundness and stability of the exchanges, and enforces these characteristics through the fair applications of the norms. *Carrel* assures:

1. The availability, presentation and delivery of organs, tissues and bones,
2. The eligibility requirements for Hospitals and Tissue Bank,
3. Acceptable behavior of participants within the site and,
4. The satisfaction of public commitments made by participants.

That is why *Carrel* could be seen as an intelligent resources management service. These resources are:

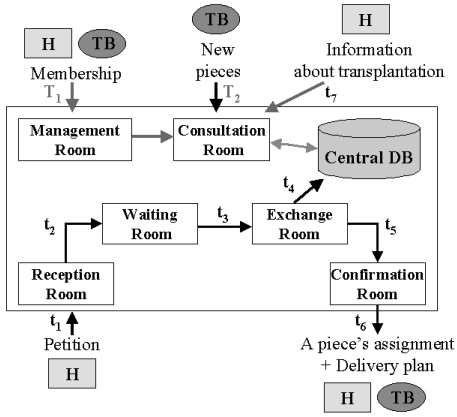

Fig. 2. The Scenarios in Carrel

Information, Organs and Tissues. The Institution has several scenarios, depicted in figure 2. There is, of course, a *Management Room* where the Institution takes care of the assignment of new memberships providing the identification number to each Hospital and is where all the *norms* are designed and enforced. And in case of conflicts among members the resolution comes from there. In this room all the rules that enforce the Institution Stability are dictated, as for example:

- Can members leave the Institution? When?
- Are there cost or penalties?
- How does it affects the Institution?

Agents have to communicate with the *Institution* and reason about the information it contains. This interaction among *Carrel* and the agents is based on a Language-Action Perspective [13],[12]. As the abilities of the agents to communicate and negotiate take an important role in our approach, we will devote the rest of this section to explain how these take place at each moment inside the *Institution*.

- **Reception Room**
  In this room, the agents have to identify themselves showing the Hospital Transplant Coordinator's electronic signature and Hospital's membership identification. This event is represented in figure 2 as t_1 and it is here where the process starts. This room is always open to new Agents with a request (see table 1).
  This room also serves as fire-wall against possible intruders to assure data protection inside *Carrel*. We will not address in this paper the security problems but of course those are issues of

a vital importance for the Institution in terms of performance and also to achieve trust among members.

- **Waiting Room**
  When the Reception Room recognizes the signature of a given Agent, it can go then to the Waiting Room. This event is represented in figure 2 as t_2. The agents have to wait here until a new negotiation is opened. This intermediate room serves to regulate traffic inside *Carrel* and to synchronize the Institution. In this room the format of the contents are revised to allow only well-formed messages to arrive at the Exchange Room. Rejected messages will cause an exit from the Institution (see table 1).
- **Exchange Room**
  This is the main scenario in *Carrel*, and it is where negotiation takes place.When a new negotiation is opened, in time t_3, the agents in the *Waiting Room* enter this room. The Exchange Room Manager Agent analyzes each agent's query and assigns a subset of the pieces offered in the Central Data Base that match its query. It is done this way for two reasons: first, to lighten the agent's work during its reasoning, and second, to keep a control of how the tissues are offered and assigned. Each piece offered to an agent has both associated an estimated procurement cost and a distribution cost, so the agent can use them when deliberating.
  When an agent has received an offer list, it can start deliberating about them, evaluating each tissue according to the matching of its needs and the tissue's characteristics using its own selection function (see figure 3). The Agent is free to reject all pieces it dislikes.
  Once the Agent has performed its deliberations, the assignment process takes place. This process uses a weighted graph that relates each Agent_i with its pieces, with the evaluation of each one provided by the Agent_i as the weight of each arc. The goal of this process is to achieve a maximum satisfaction with a minimum cost for each agent.
  After the assignment process is finished, the agents may have got a piece or not. In the case the Agent has not been assigned any piece, it will return to its Hospital to inform that there are no pieces matching its needs. If the agent succeeded in getting a piece, it will proceed to the *Confirmation Room*.
- **Central Data Base**
  It contains *Carrel*'s central data base which gathers all the available information from all the TB members. That is the TB informs the Institution about any new pieces acquired.
  After a transplant operation has been performed the transplantation center remains in contact with *Carrel* in order to provide information about the outcome. The Central Data Base gets the following information from the hospital: (a) when receiving a piece, (b) when the transplantation takes place and, (c) after three weeks. *Carrel* also keeps track of incidents in any of those steps. Analysis of this information can help to identify factors that affect the long-term outcome of transplants.
  The *Carrel*'s value increases with the growth of this data base. The proposed data structure for this data base is detailed in §5.1.
- **Consultation Room**
  The purpose of this scenario is to allow the exploitation of all the available data stored in *Carrel*'s Central Data Base (see figure 4). The security in this room has to be extreme and therefore only authorized agents will have access, as for example, in this version, only the HTC agents, OCATT and ONT agents are allowed.
  This data could also be subject to Knowledge Discovery, Data Mining and/or Machine Learning Tools.
- **Confirmation Room**
  Although an Agent_i is assigned a piece during the assignment process, it is a *provisional* assignment. The Agent_i has to confirm that he accepts the assigned Piece_k. This event starts, in figure 2, in t_5.
  There exists a time window until it is considered *definitive*. This time window is also used to allow the arrival of an *Emergency "0"* request (see §4). These emergencies have the highest priority, and when an Agent_u arrives with such a query, the whole process is stopped to let Agent_u to search throughout the total current offer, including the provisionally assigned pieces.
  When the time windows expires, the agents can return to their hospitals to inform them that they got a piece and the delivery plan. The TB is also informed about the assigned pieces that it has to deliver and the plan of delivery.
- **Planning**
  This task is performed within the *Confirmation Room*. For each organ or tissue a delivery plan

is built. One has to remember that organs and tissues are free of charge but the procurement, conservation and transport cause an expense. In many cases plans are pre-calculated or can be re-used but sometimes a plan has to be created *ex profeso* for a given piece and a pair (TB_i, H_j).

3.1 Hospitals

A Hospital is represented in *Carrel* by the Transplant Coordination Unit Agency (*UCTx*). This agency serves as interface between the surgeons and *Carrel*. When a surgeon needs some piece it makes his request through the UCTx system, which analyzes the information entered by the surgeon, adds the information about the recipient and, finally, creates a *Finder Agent*, that is, the agent that goes to the institution looking for a suitable piece.

When a *Finder Agent* returns, it communicates to the *UCTx* the result of the negotiation. If a piece has been found, then the UCTx creates a plan for the reception and transplantation.

This Agency is also responsible to give feed-back, to *Carrel* , when the piece arrives, after transplantation and three weeks after the intervention or in the case of any fatality. This feedback is made through the *Consultation Agent*, another of the agents that comprise the UCTx Agency.

4 Negotiation Norms

As an institution, *Carrel* uses a set of norms that have to be accepted by all the members and these norms have to respect the actual legislation[5]. For example, inside *Carrel*, the following rules apply:

- The pieces assignment will follow a FIFO policy since earliest use will minimize waste through degradation, that is, delivery for transplant as soon as possible.
- The emergency "0" situations will always take precedence.
- There is the obligation to inform to the Institution about each step that a piece follows (see §3).
- The TB have to commit to up-date *Carrel*'s Data Base and to follow the standard representation format for all pieces (see §5).

[5] In the Spanish case they are compiled in Royal Decree 20/70 of 1999 and, 4/11 of 1996

This last rule is not easy to enforce as many TB use very different codification procedures. Although, there exist some ongoing standardization process.

4.1 Negotiation

To describe the Negotiation process in *Carrel* we take Noriega's definition of a Dialogical Stance:

> As all interactions can be tagged by illocutions (messages), and all observable commitments will be traceable to an illocution (message), agents can be thought of as entities who *engage in dialogue* and through dialogue *coordinate actions*(cif. § 4:90 [8]).

In figure 3 we present the main flows of acceptable messages. We are assuming that an $Agent_i$ and *Carrel* engage a dialogue and not merely into a simple message-passing routine. In this case, the dialogue between the Agent and *Carrel* expresses the whole negotiation process. In figure 3 in black we depict a *standard* encounter between a Finder Agent and *Carrel* [11]. In tables 1 and 2 we present the valid messages for this dialogue.

These messages include all the possible interactions we have identified so far. Of course, the interactions of the Finder Agent and the rest of the UCTx Agents are not covered here (see [1]).

5 Tissue Bank

A Tissue Bank has several well-defined tasks. Among them, the most important are:

- Tissue procurement: all potential donors should be identified as early as possible.
- Tissue quality control: serological and other screening methods should be used to minimize the risk of transmission of infectious diseases to the recipients.
- Tissue storage: tissues have to be kept according to agreed criteria.
- Tissue distribution: a well-organized system for allocating and transporting donated tissues to the *most* appropriate recipient is important.

In the *storage* task we include the classification of the available pieces for their further distribution. Information coming from different sources has to be attached to each piece of tissue or bone in the TB as for example, data from the several laboratories, data about quality controls, *etc.*

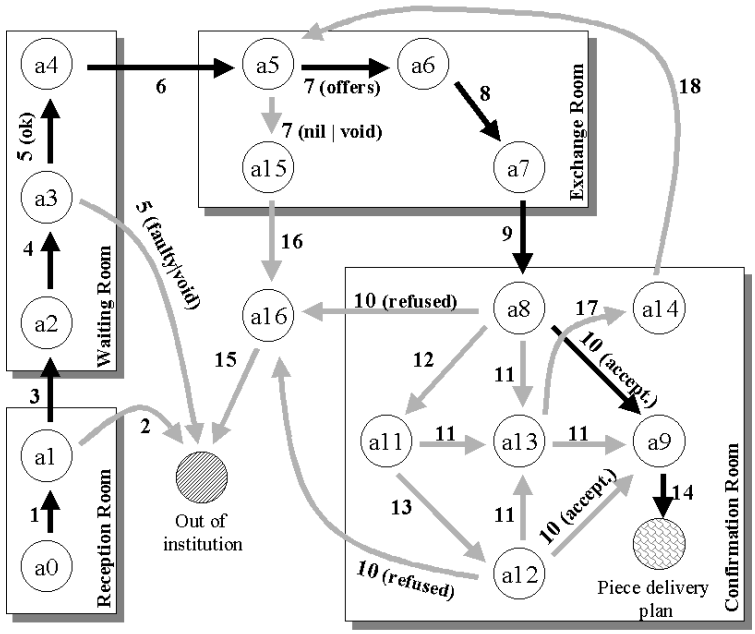

Fig. 3. Communication behavior of the Finder Agent for negotiation

Message♯	Predicate	Parameters
1	Admission	id_agent, organ|tissue, {organ_parameters|tissue_parameters}*, info_recipient, selection_function
4	petition	id_agent, petition|consultation hospital_certificate, post stamp
8	weighted_list	id_agent {id_piece weight}+
10	piece_eval	id_agent id_piece accepted|refused
15	exit	id_agent exit_reason
18	another_offer_list	id_agent

Table 1. Messages Finder Agent → Institution

5.1 Data Standarization

The organization of all the information available in the Tissues Bank is crucial for the system. A first step is to create a standard for the identification of each piece and sub-pieces. This is due to a possible fragmentation of pieces for multiple transplants (eg. a bone).

Each piece is registered in the data base of a TB and in turn it has to communicate the arrival of new acquisitions to *Carrel*'s Central Data Base using a message that follows this format:

$$PP.HHH.YYDDDD.PPPPP.CCCC \quad (5.1)$$

`PP` stands for country identification code, `HHH` is Hospital's Identification code, `YYDDDD` is the Donor's Identification code, `PPPPP` is the piece's identification code and, `CCCC` is the pieces's caducity identification code. In *Carrel* the registration identification is the same. The first three keys are the same for each piece coming from the same donor.

`YYDDDD` is an encrypted key that assures donor's[6] anonymity. The `CCCC` code has to be elaborated and accepted by all actors. In Catalonia, there exists a first approach to the description of corneas formulated by the *Cornea Transplant Consultancy Commission of the Catalan Health Service* [3].

[6] The key allows to encode 10000 donors per year which gives enough room

Message♯	Predicate	Parameters
2	deny	denied_certificate
3	accept	
5	petition_state	ok|faulty|void
6	init_exchange	
7	offer_list	{id_piece, info_piece}$^+$ |NIL|void
9	piece_offer	id_piece, cost_estimation
11	piece_reassigned_Exception	id_piece reassignment_reason
14	piece_delivery	{id_agent, id_hospital id_tissue_bank|id_hospital_donor delivery_plan}

Table 2. Messages Institution → Finder Agent

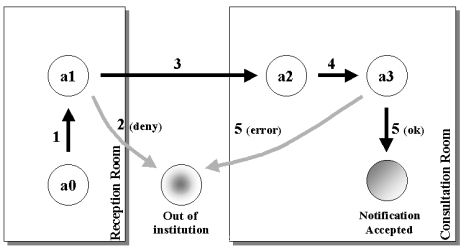

Fig. 4. Consultation Room

5.2 Consultation Room

The Consultation Room deserves a special attention as it gives access to the information contained in *Carrel*'s Central Data Base. In figure 4 we depict the message interchange that describes what happens in this scenario. Messages coming from Agents accessing the Consultation Room are shown in table 3, the answers to those are in table 4. We distinguish those messages as Cx. As said before, the access to the Consultation Room is severely limited and privilege levels can be settled in order to define different access levels.

In figure 2 we can see that there are two entrances to the Institution: (a) Reception Room and, (b)Management Room. The second only allows the entrance of the agents representing the OCATT, the ONT, those representing the TBs and the Consultation Agents of the UCTx agencies (see [1]). That means that the certificates used to access *Carrel* from Management Room are different to those used to access from the Reception Room. From the Reception Room it is impossible to access the Consultation Room.

Access to the Consultation Room grants the opportunity of tracing the life of a given Piece$_k$, using the data type described in 5.1, from its arrival into the system until three weeks after its transplantation. Also, the Consultation Room will allow, if agreed by all the members, consultation of all the available data for all transactions.

It is in this scenario where Artificial Intelligence techniques could be applied to extract new knowledge from data. For example, to predict the delivery time for a given Piece$_k$, to argue why a Patient$_i$ shall not be given Piece$_k$, etc.

6 Conclusions

Organ transplantation is the best available established technique for the treatment of end stage failure for most essential organs (liver, heart, lungs). Corneal transplantation is similarly well established and tissue transplantation, particularly bone but also skin, tendons, etc., is growing very rapidly. [7].

In view of increasing the potential success of transplantations we introduced a multi-agent based institution *Carrel* meant to mediate between hospitals and tissue banks. This institution is responsible for the collection and management of data from donors and recipients, and also it is responsible mediator in organ and tissue allocation in a region or a country.

The implementation of such *Institution* aims to optimize organ and tissues distribution whilst ensuring the most clinically effective allocation, and to support donor organ procurement to increase the supply of donor organs and tissues. *Carrel* is a first attempt to model the process and attract the attention of the different actors as Hospitals, Tissue Banks, Organ and Tissue Sharing Offices, etc. towards the potentiality of these techniques in the

Message♯	Predicate	Parameters
C1	admission	id_agent, query_function
C4	new_pieces	id_agent, {id_piece info_piece}$^+$
C5	query	id_agent
C6	transplantation_eval	id_agent id_piece id_patient

Table 3. Messages Consultation Agent → Institution

Message♯	Predicate	Parameters
C2	deny	denied_certificate
C3	accept	
C7	ack	{ok|error}

Table 4. Messages Institution → Consultation Agent

promotion, support and co-ordination of organ and tissues transplantation in the broadest sense.

An important issue for the success of Agent Mediated Institutions like *Carrel* is Trust. Not only the actors like the Hospitals, the Tissue Banks, organizations as the OCATT and the ONT but also society has to *trust* on them. As observed by Noriega [8], if Agent Mediated Institutions are going to be trustworthy, it will depend largely on how effective they are in enforcing rules of behavior. In this case, the balance between an automatic mediation and the actual situation will be, in our opinion, the first step in gaining trust. The other main issue is security. *Carrel* has to certify the security and integrity of all transactions performed on it.

Carrel aims to help in the improvement of transplantation results through scientific research.

References

1. U. Cortés, A. López-Navidad, J. Vázquez-Salceda, A. Vázquez, D. Busquets, M. Nicolás, S. Lopes, F. Vázquez, and F. Caballero. Uctx: A multiagent approach to model a transplant coordinator unit. Technical Report LSI-00-38-R, Software Department. UPC, 2000.
2. Organización Nacional de Transplantes, editor. *Informes y Documentos de Consenso promovidos por la Organización Nacional de Transplantes y la Comisión de Transplantes del Consejo Interterritorial del Sistema Nacional de Salud.* Editorial Complutense S. A., 1^{st} edition, 2000.
3. S. García-Sousa, A. López-Navidad, F. Caballero, and M.A. Viedma. Potential cornea donors in a general hospital. *Transplantation Proceedings*, 32:2607–2608, 1999.
4. The FishMarket Project. http://www.iiia.csic.es/-Projects/fishmarket.
5. A. López-Navidad, J. Kulisevsky, and F. Caballero, editors. *El donante de órganos y tejidos: Evaluación y manejo.* Springer-Verlag Ibérica, 1^{st} edition, 1997.
6. Antonio López-Navidad. Professional characteristics of the transplant coordinator. *Transplantation Proceedings*, (23):1607–1613, 1997.
7. R. Matesanz. Meeting the organ shortage: Current status and strategies for improvement of organ donation. *Newsletter Transplant*, 4(1):5–17, 1999.
8. P. Noriega. *Agent-Mediated Auctions: The Fish-market Metaphor.* Number 8 in IIIA Monograph Series. Institut d'Investigació en Intel.ligència Artificial (IIIA), 1997. PhD Thesis.
9. D.C. North. *Institutions, Instutional Change and Econonomic Performance.* Cambridge Univ. Press, 1^{st} edition, 1990.
10. Organización Nacional de Transplantes. http://-www.msc.es/ont.
11. J. S. Rosenschein and G. Zlotkin. *Rules of Encounter.* The MIT Press, 1^{st} edition, 1994.
12. M. P. Singh, A. Rao, and M. Wooldrige, editors. *Intelligent Agents IV. Agent Theories, Architectures, and Languages*, volume 1365 of *LNAI*. Springer Verlag, 1^{st} edition, 1998.
13. E. M. Verharen, F. Dignum, and S. Bos. *Implementation of a Cooperative Agent Architecture Based on the Language-Action Perspective.*, pages 31–44. Volume 1365 of Singh et al. [12], 1^{st} edition, 1998.
14. G. Weiss, editor. *Multiagent Systems.* MIT Press, 1^{st} edition, 1999.
15. M. P. Wellman. A market-oriented programming environment and its application to distributed multicommodity flow problems. *Journal of Artificial Intelligence Research*, (1):1–23, 1993.
16. M. Wooldrige. *Intelligent Agents*, chapter 1, pages 27–77. In Weiss [14].
17. The Michigan AuctionBot Project. http://-auction.eecs.umich.edu.