CARREL: AN AGENT MEDIATED INSTITUTION FOR THE EXCHANGE OF HUMAN TISSUES AMONG HOSPITALS FOR TRANSPLANTATION

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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 [7], [13] and AuctionBot [23], [21] in order[1] to assure a fair[1] distribution of resources. Carrel is an Intelligent Resources Management Service.

1. INTRODUCTION

The importance for health of a single organ and tissue donor is of first magnitude, both from assistance and economic terms. A single organ donor can satisfy the transplant of dozens of organ and tissue recipients [9]. For many of them, as observed by Lopez-Navidad, transplantation represents the only therapeutic alternative and for some their only chance for survival [8]. For example, in economic terms, for the Spanish case, the transplantation of one kidney compared with dialysis would save the patient or the social security services between 186400 and 240530 Euros.

In the last 10 years there has been, in Spain, a growing number of donors and this situation lead to the creation of *Tissue Banks* (TB). These are institutions specialized in the extraction and maintenance of tissues and bones from cadaveric donors for subsequent use in transplantation. In Barcelona, for example, there are 3 of these institutions: Hospital de la Santa Creu i Sant Pau (HSCSP), Hospital Clínic de Barcelona (HCB) and, Hospital de la Vall d'Hebrón (HVH). Spain is the first transplant organization, in the world, achieving 33 donors per million population (pmp) in 1999. Catalonia, with a population of 6 millions inhabitants, has been in the vanguard in Spain of transplantation and organ donors since transplants was first performed in 1965. In 1999 there were 37 cadaveric organ donors pmp.

Our interest is to try to understand how organs, tissues and bones are assigned among recipients and to create an Institution to coordinate the assignation of those goods. The altruism of individuals not withstanding, there still remains competition for limited resources. This fact allows us to think of the assignation problem as a special kind of *negotiation* among autonomous agents with conflicting interests. For example, two agents each representing a hospital competing for a single piece of tissue.

Our proposal is to build an Agent Mediated Institution to regulate and speed up the assignation of tissues and bones. The main objectives of this Institution[1] are: (1) to guarantee a fair and equable 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 exploring 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 advantage of a single negotiation protocol, the standardization of information and using the communication facilities provided by the Internet.

The Internet is allowing many new ways of exchange and changing many conventions and procedures. Not only the actual organs and tissues exchanges have to be adapted to this new environment but new ways, services and practices of exchanges for these goods have to appear. Of course, the exchange of tissues has to observe the local, national and European Union legislation (see the reports of the ONT[2] in [4] and the recommendations of the Transplant Experts Committee in [10]).

1.1. ORGANIZATION

This article is organized as follows. First, in section §2 we will briefly describe *Carrel*, an explanation of *Carrel*'s scenes is given 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

[1] After 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] The Organizacion National 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 organ, tissues and bone marrow.

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 *Carrel*'s global view.

From the point of view of multiagent interactions, organ and tissue exchange 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 [22],[20]. A related approach for monitoring medical protocols using autonomous agents is described in [1].

Organ and tissue exchange could be classified as a Task Oriented Domain (TOD). In those domains agent activity can be defined in terms of a set of tasks that it has to achieve [16].

Agents inside *Carrel* have to represent a Hospital$_j$ that needs a single piece for transplantation (eg. a cornea or a heart valve) and they have to

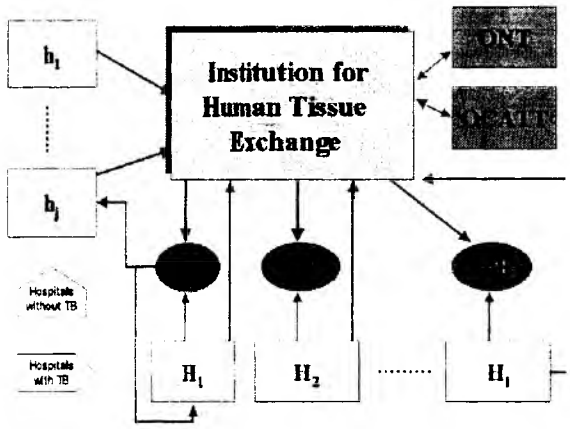

Figure 1. Carrel: An Agent Mediated Institution for Tissues Assignment

present this petition to the Institution. This petition will be formulate as a message (see table III). If there is a set of available pieces matchin the request, those will be presented, following the Institution's norm (see §4), to the Agent to choose in terms of its internal *selection functio* (see [3]). This function varies according to (1) the kind of organ, tissu and/or bone, (2) the recipient's needs and information, and (3) th surgeon and/or hospital transplant criteria.

This matching function is not always easy to define as the selectio criteria for a given piece of tissue are continuously modified, and ma range from very permissive and elastic to very selective and stric Moreover, transplant criteria vary ostensively even between transplan teams from the same geographical area an substantially between mor distant transplantation teams [9]. This observation allows us to think i the creation of a trading agent representing each transplantation tean and for each kind of organ, tissue and/or bone.

Although the exchange transaction of organs and tissues *only* re quires from the Hospital's agents the application of a Selection Functio when demanding a piece, and from Tissue Banks *only* to choose th moment when submit the information about their organs and tissue these decisions -if rational- involve complex deliberative processes as observed by Noriega for the Auctions' case [13].

Complexity comes not only from the amount of information Hospital's agents have to access or need to take into account in the transaction, but also from the fact that the actual conditions of deliberation are constantly changing and are uncertain - new pieces are arriving to the system, the number of Hospital's agents is variable, the recipient conditions are dynamic, etc and deliberation is time-bounded: the final assignment of a piece depends on the final acceptation given by the Hospital. So, the decision-making process under these conditions may be quite complex.

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 (ONT) [15] and the Organització Catalana de Transplantaments (OCATT). The precise role of OCATT and ONT for the Catalan case is described in [8].

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. We are two main classes of hospitals authorized, by the government, to perform transplants: those having a Tissue Bank as for example HSCSP, and those without one (see figure 1). During the explanation we will only make reference to the first class.

Each Hospital has a Transplant Coordination Unit Agency called *UCTx* that allows to interact with the Institution (see §3.3 in this paper for more information about hospitals, see [3] for a deeper explanation of the UCTx Agency). Inside a hospital an important actor in the transplantation process is the Hospital Transplant Coordinator (HTC), who takes the responsibility for the identification and screening of donors, organs and tissues extraction and their maintenance [9]. Also s/he participates very actively on the distribution of organs[4], tissues and bones.

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) keep tracking of the transplanted pieces.

In most of the cases, as shown in figure 1, the HTC does not take care of the Tissue Bank as most Hospitals do not have a TB. In other cases the Tissue Bank management is not assigned to the HTC. The HTC we are describing corresponds to the one described in [9] and [8].

The agents that come into *Carrel* represent each Hospital Transplant Coordinator acting in their name in the process of negotiating for pieces for a transplant. Each HTC is modeled as an Agency (see [3]) that has different agents for each kind of piece and it is also able to specialize the Selection Function (see §4.2) assigned to an Agent$_i$ for a given Recipient$_k$.

The negotiation for a piece in *Carrel* takes place in the Exchange Room (see figure 2). There Agents deliver a sealed envelope containing all the required information in the following format:

```
<carrel-request>
  <hospital>HHH</hospital>
  <piece>PPPPP</piece>
  <urgency>0|1</urgency>
```

[4] For organ procurement and exchange see [10]

```
    <recipient-info>....</recipient-info>
    <selection-function>....</selection-function>
    <htc-signature>[E-SIGNATURE]</htc-signature>
</carrel-request>
```

(2.1)

HHH stands for hospital identification code (which is provided by the Institution), PPPPP is the desired piece identification code (see 5.8) and *urgency* = 0 means delivery in less than 24 hours. TTTTT is the maximum date the recipient can wait to receive the piece (if applicable). The `<recipient-info>` tag has associated the recipient's relevant information, and the `<selection-function>` tag contains the Selection Function (see §4.2), which is private information. It has also the Hospital Transplant Coordinator's electronic signature, as encrypted information that is placed instead of `[E-SIGNATURE]`.

The OCATT and ONT do participate in this scenario and their role is as observers of the whole process and have to be considered as 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,

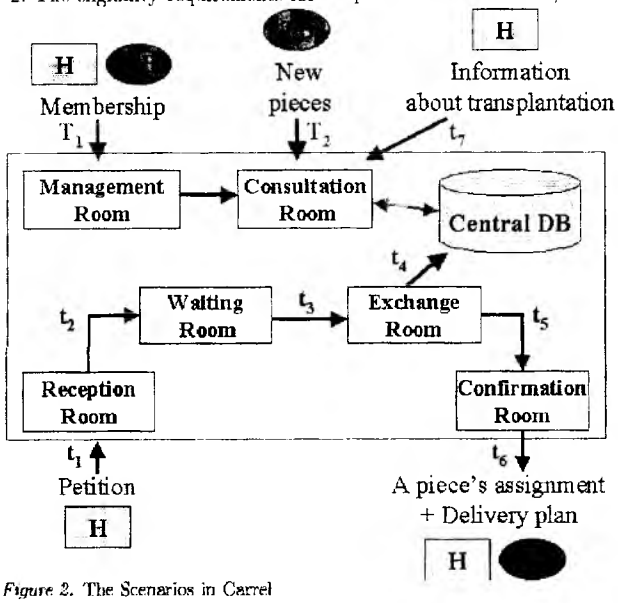

Figure 2. The Scenarios in Carrel

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: Information, Organs, Tissues, and Bones. 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 it is where all the *norms* are designed and enforced. And in case of conflicts among members the resolution comes from there [11]. 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 [19],[17]. As the agents abilities to communicate and negotiate take an important role in our approach, we will devote the rest of this section to explain how negotiation and communication among agents take place at each moment inside the *Institution*.

3.1. Scenarios in Carrel

The most important scenario, in *Carrel*, is the *Exchange Room*, where negotiation takes place. Agents arrive there after passing through the *Reception Room* and waiting in the *Waiting Room*.

The *Planning* scenario is the last step in the assignment process. Here the TB is communicated the assigned pieces that it has to deliver and it also communicates to the Hospital that was asking for the piece with its identification and the plan for its delivery. Also the TB receives this delivery plan.

- **Reception Room**

  In this room, the agents have to identify themselves showing the Hospital Transplant Coordinator's electronic signature and Hospital's membership identification (inside the sealed envelope, see 2.1). 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 III).

  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$_i$, 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 round 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 III).

- **Exchange Room**

  As said before, this is the main scenario in *Carrel*, and it is where negotiation takes place. When a new negotiation is opened, at 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

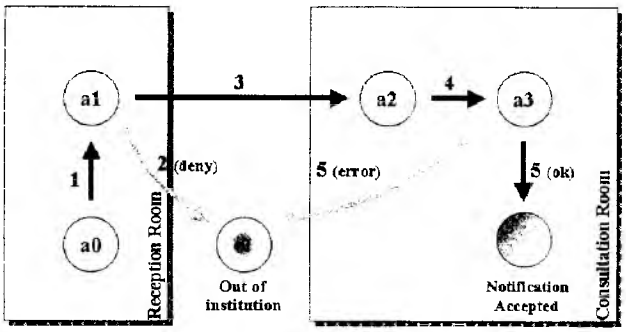

Figure 3. Consultation Room

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 5). 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 a piece is received, (b) when the transplant takes place and, (c) the recipient's evolution after three weeks. *Carrel* also keeps tracks 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 permit the exploitation of all the available data stored in *Carrel*'s Central Data Base (see figure 3). 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 permit 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 $(\text{TB}_i, \text{H}_j)$. An important item of information, for the scheduling agents, is the `time-to-deliver` provided in the `carrel-request` (see 2.1).

As observed by Castelfranchi *et al* [2], norms (see §4) may have impact on plan generation: an adopted norm may lead to focus on generation of specific types of actions and plans, and exclude certain other actions and plans from being generated at all.

3.2. 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 3 we depict the message interchange that describes what

Table 1. Messages Consultation Agent → Institution

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

happens in this scenario. Messages coming from Agents accessing the Consultation Room are shown in table I, the answers to those are in table II. 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 [3]). 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 5.8, 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.

3.3. 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.

A special situation arises when the Hospital Transplant Coordinator from any center of National Health System detects the existence of a potential organ donor: s/he should communicate it to the central office of the ONT or to the OCATT if s/he is in the Catalan territory. In our case the HTC agent will communicate this to the OCATT agent in the Institution who in turn will distribute this information as appropriate.

Also, our implementation has to reflect the infrastructure and personnel of a Transplant Coordination Unit (UCTx) which permits to successfully culminate any organ and tissue procurement and extraction process for transplantation [8]. That is why each UCTx is modeled as an Agency (see figure 4) that has different agents to deal with the request

Table 2. Messages Institution → Consultation Agent

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

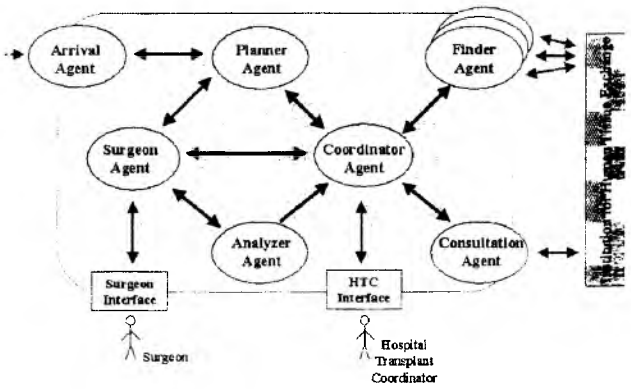

Figure 4. The Transplant Coordination Unit's Agensy

of each kind of piece, and it is also able to specialize the Selection Function (see §4.2) for a given recipient using the relevant information coming from the surgeon and the recipient's data.

The Agency comprises a *Coordinator* or HTC, and other agents, each one competent in a specific task. The *Coordinator* distributes tasks among the other agents in this Agency.

The *UI Agent* is responsible for communicating with the human users (the surgeons and/or Hospital Transplant Coordinator). The information given to this agent will be passed to the *Analyzer Agent*. specific to each piece, this agent will check if the information was properly entered, that is, if all the characteristics were entered, if the values are consistent following a given protocol. If there is some data missing, it informs the *UI Agent* who will ask the user to enter prior to validation. When the *Analyzer* has all the information required, a new *Finder Agent* is created by the HTC. This agent will be the one going to the Institution to look for the desired piece. The *Finder Agent* is provided with a sealed envelope with all the information required (ie. hospital's information, patient data, *etc*).

When a *Finder Agent* returns, it communicates to the *Coordinator* the result of the negotiation. If a piece is found, the information is passed to the *Planning Agent* that will make up a logistic plan for the reception and transplantation. This information must go to the surgeon that will perform the transplantation.

If no piece was found, it asks the *UI Agent* to inform the user (surgeon) of such failure. This will provoke an *impasse* that has to be solved by the Hospital Transplant Coordinator in person.

This Agency is also responsible for giving feed-back, to *Carrel*, when the piece arrives, after transplantation and three weeks after the intervention or in the case of any fatality.

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 §3.1).

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

- The TB have to commit to up-date *Carrel*'s Data Base and to follow the standard representation format for all pieces (see §5).

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

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 [13]).

In figure 5 we present the main flows of acceptable messages. We are assuming that an Agent; and *Carrel* engage a dialogue and not merely a simple message-passing routine. We distinguish two types of dialogue that a Finder Agent could start: a) with *Carrel*. This dialogue expresses

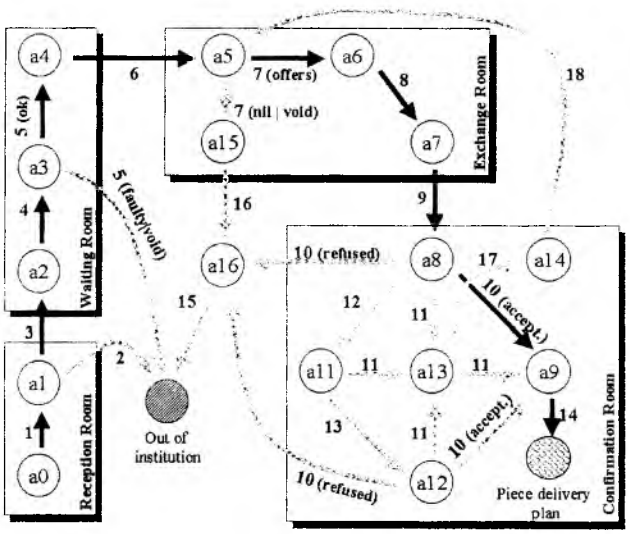

Figure 5. Communication behavior of the Finder Agent for nego tiation

the whole negotiation process. In figure 5 in black we depict a *standard* encounter between a Finder Agent and *Carrel* [16]. In tables III and IV we present the valid messages for the first dialogue.

Table 3. Messages Finder Agent → Institution

Message	Predicate	Parameters
1	Admission	id_agent, organ | tissue, {organ_parameters | tissue_parameters}*, info_recipient, selection_function
4	Request	id_agent, petition | consaltion, hospital_sertificate, 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 4. Messages Institution → Finder Agent

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_reson
14	piece_delivery	{id_agent, id_hospital id_tissue_bank | id_hospital_donor delivery_plan}

Table 5. Messages Finder Agent → Hospital

Message	Predicate	Parameters
16	no_offer_Exeption	void | nil
12	I_cannot_decide_Exeption	id_piece, info_piece
17	piece_offer_reassigned_Exeption	ressignment_reason

The second type of dialogue is between the Finder Agent and its Hospital more specifically with its HTC (see tables V and VI).

These messages include all the possible interactions we have identified so far. Of course, the interactions inside a Hospital are not covered (see 3.3).

Table 6. Messages Hospital → Finder Agent

Message	Predicate	Parameters
13	piece_offer_decision	accept | refuse

4.2. The Selection Function

Here we introduce the description of a *Selection Function*, one of the items that comprise the envelope the *Finder Agent* carries to the Institution. We will use as an example the request for a cornea to illustrate our ideas.

Corneal transplants are very common in the United States: about 46.000 are performed each year, that is 178 pmp [12]. In Spain, in 1999, the corneal transplants were 41 pmp. For 1999, in Catalonia, there were 345 transplants, that is 141 pmp, and in the first 5 months of year 2000 there are 183 pmp [15].

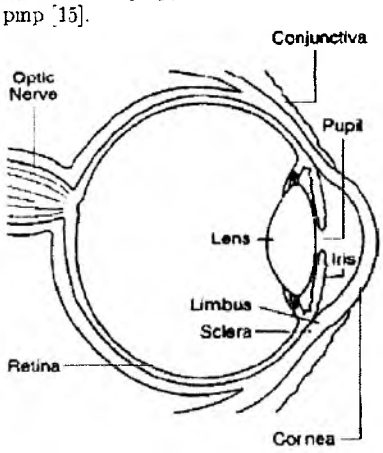

Figure 6. The Eey

A corneal transplant involves replacing a diseased or scarred cornea with a new one. In corneal transplant surgery, the surgeon removes the central portion of the cloudy cornea and replaces it with a clear cornea (see figure 6), usually donated through an Tissues Bank (TB). A trephine is used to remove the cloudy cornea. The surgeon places the new cornea in the opening and sews it in place.

A study supported by the National Eye Institute (NEI) suggests that matching the blood type, but not tissue type, of the recipient with that of the cornea donor may improve the success rate of corneal transplants in people at high risk for graft failure. Approximately 20 percent of corneal transplant patients–between 6000-8000 a year–reject

their donor corneas. The NEI-supported study, called the Collaborative Corneal Transplantation Study [6], found that high-risk patients may reduce the likelihood of corneal rejection if their blood types match those of the cornea donors. The study also concluded that intensive steroid treatment after transplant surgery improves the chances for a successful transplant.

The *Selection Function* is a private piece of knowledge given by surgeons to guide the search, in this case, for suitable corneas made by the *Finder Agent*.

The *Selection Function* is composed of a set of rules, each one a constraint the selected piece (*e.g.* a cornea) has to satisfy. Some of these rules belong to the policy of the hospital transplant unit, and the rest of the rules are introduced by the surgeon who can set the constraints needed for a given recipient.

A rule of the *Selection Function* for a cornea can include:

- predicates about the piece: predicates that describe the constraints the selected cornea has to satisfy, such as the age of the donor or the density of endothelial cells in the cornea.
- predicates about the Tissues Bank: predicates that can set constraints about the Tissue Bank preferred by the surgeon or the hospital.
- predicates about the cost of the cornea: a predicate that can set a maximum cost for the selected cornea. This cost is related only to the cost of the cornea extraction and preservation process, and it is paid through a clearing house by the hospital who receives the cornea. An example of such predicate is $(< \ Cost \ 600euros)$.

As an example let us describe an imaginary recipient r with the predicate rule P_r as:

$$P_r = \{ (= \ Age_r \ Young) \wedge (= \ Blood\_Type_r \ A) \wedge (= \ Sex_r \ Male) \wedge ... \} \quad (4.2)$$

and he needs a cornea for transplantation. The UCTx will prepare an envelope with the petition that will include the encrypted recipient information shown in 4.2 and the *Selection Function* shown in rule 4.3:

$$(= \ Age_d \ Young) \wedge (= \ TB \ \text{HSCSP}) \wedge (> \ EC_d \ 2000/mm^2) \quad (4.3)$$

where Age_d stands for the donor's age, TB stands for Tissue Bank and EC_d stands for the Endothelial Cells density in the donor's cornea. Of course, each institution could specialize and customize the Selection Function to fit with their policies. For example, in those countries where donors are in limited supply, to ask for $(> \ EC_d \ 2000/mm^2)$ and $(= \ Age_d \ Young)$ may exclude all available corneas in a TB so the UCTx should lower these constraints to some other more *acceptable*.

If we modify the recipient characteristics in 4.2 by doing $(= \ Age_r \ Old)$ then we can have the following Selection function:

$$(= \ TB \ \text{HSCSP}) \wedge (> \ EC_d \ 2000/mm^2) \quad (4.4)$$

which in turn is more *flexible* than 4.3.

As each kind of transplant procedure (Cornea Transplant, Lamelar Transplant, Keratoconus Transplant...) has different needs, there will be different rules for each one, and this means different selection functions. If we add to 4.2 the following information $(= \ Transplant \ K)$, where K stand for Keratoconus, then 4.3 will change to:

$$(= \ Age_d \ Young) \wedge (= \ TB \ \text{HSCSP}) \wedge (> \ EC_d \ 2800/mm^2) \quad (4.5)$$

or even to

$$(= \ Age_d \ Young) \wedge (= \ TB \ \text{HSCSP}) \wedge (> \ EC_d \ 2800/mm^2) \wedge (= Erosion\_Ep_d \ False) \quad (4.6)$$

where $Erosion\_Ep_d$ expresses whether there is erosion in the donor's Epithelial layer of the cornea. It is possible to specialize rule 4.3, 4.4, 4.5 and 4.6 by adding the following predicates

$$(= \ HLA_d \ DR) \wedge (= \ Blood\_Type_d \ AB0)$$

The HLA[6] predicate will measure the histocompatibility between the Donor and the Recipient, although this is only important when a potential recipient had suffered from previous graft rejections.

Surgeons or the Hospital Transplant Coordinator can introduce other constraint rules about the cornea, such as the time it has been in preservation at the Tissues Bank:

$$(= \ Age_r \ Young) \wedge (< \ Hours\_In\_TB \ 72) \quad (4.7)$$

as some surgeons think that corneas with more than 3 days (72 hours) inside the TB are not good choices for a young recipient.

The surgeons can easily create their own rules to build their own selection functions by means of a rule editor in the *Surgeon Interface*. With this editor a surgeon can compose a rule, and then associate a weight to each rule. These weights allow the *Finder Agent* to know which of the rules are more important than others while it is searching for a cornea and, the weights allow to qualify each piece.

5. Tissue Bank and Data Standarization

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. transporting donated tissues to the *most* appropriate recipient is important.

Most of them are related with those tasks realized by the UCTx (see §3.3). From our point of view the model of a TB becomes interesting when it is managed by the Hospital Transplant Coordinator. 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.*

5.1. Data Standarization

The organization of all the information available in the Tissue Bank is crucial for the system. A first step is to create a standard for the identification of each piece and sub-pieces[7]. 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:

```
<carrel-piece>
  <state>SS</state>
  <piece>PPPPP</piece>
  <hospital>HHH</hospital>
  <donor>DDDD</donor>
  <caducity>CCCC</caducity>
</carrel-piece>
```
(5.8)

SS stands for state identification code, HHH is Hospital's Identification code, DDDD is the Donor's Identification code, PPPPP is the piece's identification code and, CCCC is the piece's caducity date. In *Carrel* the registration identification is the same. The first three keys are the same for each piece coming from the same donor.

DDDD is an encrypted key that assures donor's anonymity. The PPPPP 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* [5].

6. Conclusions

Organ transplantation is the best available established technique for the treatment of end stage failure for most essential organs (liver, heart, lung, kidney). Corneal transplantation is similarly well established and tissue transplantation, particularly bone but also skin, tendons, etc., are growing very rapidly [10].

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; 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 suchas Hospitals, Tissue Banks, Organ and Tissues Sharing Offices, etc. towards the potentiality of these techniques in the 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* them. As observed by Noriega [13], 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.

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