



## UCTx: A Multi-Agent System to Assist a Transplant Coordination Unit

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**Abstract.** We present a system called *UCTx* designed to model and automate some of the tasks performed by a Transplant Coordination Unit (*UCTx*) inside a Hospital. The aim of this work is to show how a multi-agent approach allows us to describe and implement the model, and how *UCTx* is capable of dealing with another multi-agent system (*Carrel*, an Agent Mediated Institution for the Exchange of Human Tissues among Hospitals for Transplantation) in order to meet its own goals, acting as the representative of the hospital in the negotiation. As an example we introduce the use of this Agency in the case of Cornea Transplantation.

**Keywords:** agent mediated institutions, negotiation, tissues bank, transplants

### 1. Introduction

In the procurement of human organs, tissues and/or bones for transplantation the key role of a Transplant Coordination Unit (*UCTx*) attracted our attention because of its complexity. We follow the work of López-Navidad et al. [1] to describe all those tasks. During a single procurement or transplant episode many professionals, involved in a variety of medical acts, administer medical care. In this process health care administration personnel, health care professionals and social care professionals interact with health-related information that is complex, heterogeneous and, maybe, geographically distributed. We saw this *UCTx* as a good example of a multi-agent system that has to interact not only with another multi-agent systems as the *Carrel* institution [2] but also with other non-software agents, that is, actors of different nature such as: Donors, Surgeons, Human Transplant Coordinators and organizations as the Organització Catalana de Transplantaments (OCATT) and the

Organización Nacional de Transplantes (ONT) [3].<sup>1</sup> Each agent has different needs in terms of information access, security, and quality of service, and is involved in different medical acts and healthcare procedures.

*Carrel* is an Agent Mediated Institution designed to allow the distribution of human organs, tissues and/or bones for transplantation. It is an Intelligent Resources Management Service. The central idea is to bring all the information from the different Tissue Banks into *Carrel*, so Agents representing different Hospitals can access the Institution and negotiate for the pieces a given Hospital needs for a given transplantation. Those Agents have to accept *Carrel's* norms of negotiation. This fact determines the co-operative nature of the Institution.

#### 1.1. Related Work

Medical Domain has been always a fertile area for Artificial Intelligence applications. In the last years

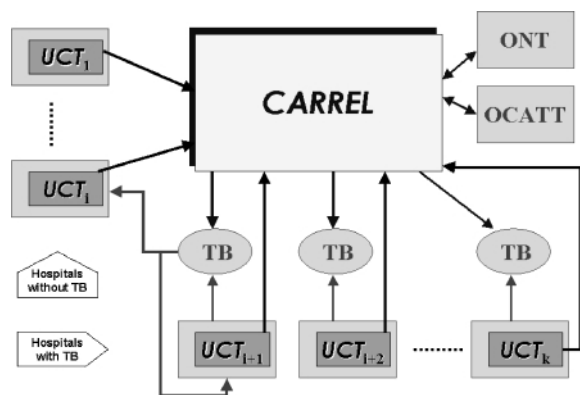


Figure 1. Interactions among Carrel, UCTx, the ONT and OCATT.

Aut. Pls. provide citation of Fig. 1.

sophisticated knowledge-based systems have been introduced and there exists a lot of literature on applying different techniques, tools and available knowledge to enrich the reasoning process of those systems, see for example [4]. But this is not the case for transplantation, so we have to rely in the re-use of solutions/approaches to try to solve our problem.

For the Knowledge Representation and Ontology construction for the medical domain we follow the work developed in GRAIL [5]. A comprehensive set of Internet resources for medical terminology is compiled in [6].

The work of Decker [7] on the design of coordination mechanisms for groups of agents applied to Hospital scheduling is clear antecedent for our work. For planning in the medical domain we follow the work of Miksch [8]. The ideas about the implementation of medical protocols follow the work of Pattison-Gordon et al. [9]. A related approach for monitoring medical protocols is described in [10]. We do not have news from other multi-agent systems applied to Transplants.

For a good survey on Autonomus Agents in Health Care see [11] and, the work of Lanzola et al. related to cooperative agents in Medical applications [12].

### 1.2. Organization of this Paper

In Section 2 we explain in detail the architecture of UCTx and we briefly address some security issues. In particular, in Section 2.2, we explain the exchanges of information among the different agents.

In Section 3 we give a practical example of the possible application of UCTx studying the case of

Cornea Transplantation, including an explanation and examples of the Selection Function introduced in Section 3.1. Finally, in Section 4, we present some conclusions.

## 2. UCTx: The Transplant Coordination Agency

Our implementation of an UCTx has to reflect the infrastructure and staff of a real Transplant Coordination Unit which allows the successful conclusion of an organ or tissue<sup>2</sup> procurement and extraction process for transplantation [1]. But it also includes new procedures designed to support the distributed computational system. In addition, it deals with the management of the requests for pieces made by the surgeons in order to transplant them into recipients and, it has to follow the sanitary and economic policies that the Hospital dictates.

The guidelines for this work are the existing protocols in the Hospital de la Santa Creu i Sant Pau, in Barcelona. Guideline could be defined as a method that identifies *actions* to be performed and *conditions* that govern when it is appropriate to perform them [9]. Protocols are important for improving quality assurance, for standardization in clinical practice, for guiding data collection, for better management, for improving decision support. All these reasons support our choice to create UCTx as a multi-agent system where each agent adopts a role and implements one or more protocols or its tasks help in the implementation of a protocol. And we are expecting that those protocols are shared by any other UCTx implementation or by any Transplant Coordination Unit.

The UCTx implementation has been developed in JADE<sup>3</sup> [13], a framework to create agent platforms that implements all the agent management and communication protocols, leaving to programmers the definition of the agents' internal logic and their behaviors. Each hospital owns a JADE platform (a UCTx platform) that communicates with Carrel. We expect to have UCTx and Carrel communication fully operational in June 2001. Other actors as ONT and OCATT will be connected later.

Transplants information is considered high-risk as it includes sensitive information about people (donors and recipients). So the UCTx and Carrel systems have to observe the local, national and European Union legislation on transplants (see the reports of the ONT in [14] and the recommendations of the Transplant Experts Committee in [15]). It also follows the European

directives and the Spanish law on personal data protection [16–18]. In particular, both have to assure confidentiality and integrity of patient and donor’s data and privacy. This is a long-standing issue in health care that acquires new facets with use of Electronic Medical Records (EMR). One of the benefits of using electronic records is that it assures access for authorized and authenticated users and helps keeping track as demanded by law. Donors and patients have to trust that the information about them may not be used for any purpose beyond that for which it was collected by *UCTx*. To compare the situation in US see for example the report elaborated by the Institute of Medicine [19].

*UCTx* is an Agency designed to be included among the public services that AgentCities initiative will offer [20]. AgentCities is an EU funded research project.

### 2.1. Description of the Agency

A *UCTx* is modeled as an Agency (see Fig. 2) that has several agents, each one competent in a specific task and with its own role and goals to achieve [21]. The Agency is composed of a *Coordinator Agent*, *Surgeon*, *Analyzer*, *Finder*, *Planner*, *Consultation* and *Arrival* agents.

We can identify the following fundamental services that *UCTx* should provide to those agents:

1. Information confidentiality
2. Information integrity
3. Dynamic accessibility

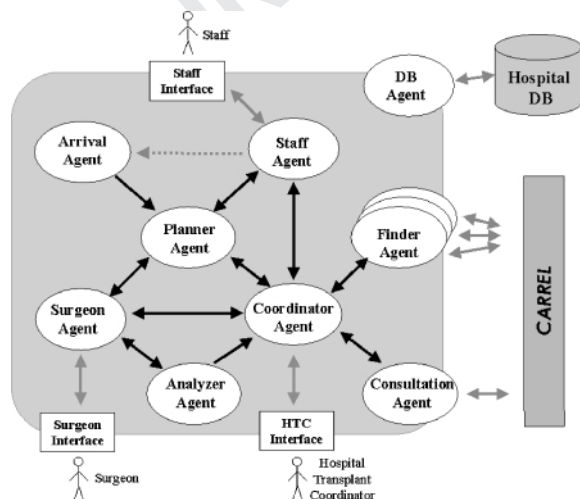


Figure 2. The Transplant Coordination Unit’s Agency.

The first two items are related to data security. As each (software or non-software) agent has a certain role in the system, we are choosing a role-based access mechanism for data confidentiality control [22] (that is, different roles have different views of the data). The data integrity is delegated to the data base controller. The last item is related with the challenge to design and develop clinical systems which are intuitive to use and adequately expressive to satisfy a number of broad requirements: clinical generality, medical expressiveness, operational flexibility, soundness and safety, verifiability and support for reusability. There exist some efforts in this line as GRAIL [5] or PRoforma [23] that we will follow.

The *Staff Agent* represents any member of the staff involved in transplants (exception are the surgeons and the Hospital Transplant Coordinator, that have an special agent to represent them). The *Staff Agent* helps the people to plan their daily tasks, acting as their electronic dietary and also letting them to receive the messages sent by the Hospital Transplant Coordinator through the *Coordinator Agent* (see message H30 in Table 16). This agent also gives, for each person, access to the clinical information of patients in their care. The *Staff Agent* can have one or several interfaces for a given user, depending on their needs and hardware available. The most powerful one is a computer program that gives all the services mentioned and which the user can adapt to their specific needs of information detail and presentation format. However, other electronic devices such as beepers or mobile phones can be used to give a subset of the functionalities (such as the alarm messages). In the future, more powerfull mobile devices would allow to include more functionalities in them.

The *Surgeon Agent* extends the *Staff Agent* functionalities to be used by surgeons. It is responsible of communicating with the surgeons through the *Surgeon Interface* and it collects and formalizes the requests for pieces for transplant. Each request has to include the relevant information about the patient, the required piece, optional medical and economic restrictions and the *Selection Function*. The *Surgeon Agent* is able to specialize the *Selection Function* for a given patient using the relevant information coming from the surgeon and the patient’s data (see Section 3.1). This function provides a way to evaluate each piece for a given offer in the *Institution<sup>4</sup> for Human Tissue Exchange*. The *Institution*, in this case *Carrel* [2], assigns the pieces to the different competitor finder agents, one for each

Table 1. Messages Surgeon Agent → Analyzer Agent.

Message#	Predicate	Parameters
H1	piece_request	id_request, id_piece, piece_params, info_recipient, preferences, urgency_level

Table 2. Messages Analyzer Agent → Surgeon Agent.

Message#	Predicate	Parameters
H2	analysis_result	id_request, ok   (error, reason)

Table 3. Messages Analyzer Agent → Coordinator Agent.

Message#	Predicate	Parameters
H3	valid_piece_request	id_request, id_piece, piece_params, info_recipient, preferences, urgency_level

Table 4. Messages Coordinator Agent → Finder Agent.

Message#	Predicate	Parameters
H4	init_request	id_request, id_piece, piece_params, info_recipient, preferences, urgency_level
H5	stop_request	id_request, reason
H6	piece_problem_answer	id_request, new_preferences   accept   refuse

Table 5. Messages Finder Agent → Coordinator Agent.

Message#	Predicate	Parameters
H7	piece_assignment	id_request, (piece_info, delivery_plan)   none
H8	piece_problem_question	id_request, info_problem

hospital and piece, maximizing the satisfaction degree of each request.

The *Surgeon Agent* sends the request to the *Analyzer Agent* (see message H1 in Table 1). This agent, specific for each kind of piece, will check if the information was properly introduced, that is, if all the characteristics needed were entered, and if the values are consistent following a given protocol. If there is some data missing, it informs the *Surgeon Agent* who will ask the surgeon to enter or to modify the data in order to validate it. When the *Analyzer* has all the information required, it sends the request to the *Coordinator Agent* (see message H3 in Table 3).

The *Coordinator Agent* is responsible for the distribution and coordination of the different tasks that make up the whole process. The *Hospital Transplant Coor-*

*inator* in person can communicate with this Agent through the *Coordinator Interface*, and control the behavior of the agent. The *Coordinator Agent* has the following tasks:

1. to coordinate all the agents involved in each transaction.
2. to check all the surgeons' requests for tissues to ensure they meet the hospital protocols.
3. to create, for each checked request, a new *Finder Agent* (see message H4 in Table 4), that will be the one going to the *Institution* to look for the desired piece. The *Coordinator Agent* will give to the *Finder Agent* the request inside an electronic sealed envelope (see Section 2.2).
4. to keep records of all the piece requests made by the hospital in representation of its surgeons.

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Table 6. Messages Surgeon Agent → Coordinator Agent.

Message#	Predicate	Parameters
H9	piece_problem_answer	id_request, new_preferences   accept   refuse
H10	query_request	id_query, info_request
H11	transplant_info	id_request, transplant_data
H12	stop_request	id_request, reason

5. to give feed-back to the *Institution* (see [2]) when the piece arrives, after transplantation and three weeks after the operation, or in the case of any fatality.
6. to give feed-back of all the information about tissue requests (surgeon who made the request, request status and so on) the *Hospital Transplant Coordinator* wants to know in real-time or also by a query in the *Coordinator Interface*. All the feedback is displayed through the mentioned *Coordinator Interface*, which also allows the *Hospital Transplant Coordinator* to set the amount of real-time information he wants to be displayed.
7. certify that any access to the hospital's medical data is performed by an authorized agent.
8. to create, for each query requesting information about tissues, a new *Consultation Agent* (see message H13 in Table 7), that will be the one going to the *Institution* to ask for the desired information.

The *DB Agent* is the one which manages the access of the other agents to the Hospital Database, following the role-based access policy mentioned back in Section 2.1. It has to verify that each access to the clinical data made from the agents in *UCTx* is authorized. The *Finder Agent* is provided with a sealed envelope (see Section 2.2) with all the information required (i.e. hospital information, patient's data, selection function, etc.). When a *Finder Agent* returns from *Carrel*, it communicates the result of the negotiation to the *Coordinator Agent* (see message H7 in Table 5). If a piece is found, the *Coordinator Agent*, as part of its agent coordination task, passes the delivery plan proposed by the *Institution* and the relevant information about the request to the *Planning Agent* (see message H17 in Table 11), which will make up a logistic plan for the reception and transplantation. This information has to arrive to the surgeon that will perform the transplant, too. If no piece was found, the *Coordinator* asks the *Surgeon Agent* to inform the surgeon of such failure. The surgeon can then revise and resubmit the request,

Table 7. Messages Coordinator Agent → Consultation Agent.

Message#	Predicate	Parameters
H13	query_request	id_query, info_request

Table 8. Messages Consultation Agent → Coordinator Agent.

Message#	Predicate	Parameters
H14	query_result	id_query, info_result

or perhaps this can provoke an impasse situation that can only be resolved by the *Hospital Transplant Coordinator* in person. The *Surgeon* and the *Coordinator* agents can stop the process of a request at any moment, if needed.

The *Planner Agent* is responsible for creating the transplant plan, that is, finding a surgery room to match the arrival time of the piece and the surgeon's available schedule. The *Planner Agent* can send several proposals to the surgeon through the *Surgeon Agent* (see message H15 in Table 9). When the surgeon agrees with one of them, the *Planner* will carry out the transplant plan and will also send a message to the *Coordinator Agent*. Otherwise, the *Surgeon Agent* can re-use a given proposal or to create its own proposal and then send it to the *Planner*. If the proposal cannot be carried out, the *Planner* can ask for help to the *Hospital Transplant Coordinator* in person and/or notify the problem to the surgeon. The special characteristics of planning in the Medical Domain are discussed by Miksch [8]. We are following Decker's approach for task planning [7].

The *Arrival Agent* is responsible for updating the *Planner Agent* about events that can change the delivery plan (see messages H23 and H24 in Table 13), events that can occur while the transportation of the tissue is made from the Tissue Bank to the Hospital. Then the *Planner* will be able to modify the delivery or the transplant plans dynamically. That is of special interest when there are problems with the delivery (for

Table 9. Messages Planner Agent → Surgeon Agent.

Message#	Predicate	Parameters
H15	ask_surgeon_availability	id_request, {time_ini, time_end}*, id_piece

Table 10. Messages Surgeon Agent → Planner Agent.

Message#	Predicate	Parameters
H16	tell_surgeon_availability	id_request, time_ini, time_end*, id_piece

Table 11. Messages Coordinator Agent → Planner Agent.

Message#	Predicate	Parameters
H17	planning_request	id_request, delivery_plan, info_request
H18	query_request	id_request, info_request
H19	query_result	id_request, info_result

Table 12. Messages Planner Agent → Coordinator Agent.

Message#	Predicate	Parameters
H20	planning_answer	id_request, delivery_plan, transplant_plant
H21	query_request	id_request, info_request
H22	query_result	id_request, info_result

Table 13. Messages Arrival Agent → Planner Agent.

Message#	Predicate	Parameters
H23	piece_reception	id_request, id_piece, state
H24	transport_problem	id_request, info_problem

Table 14. Messages Staff Agent → Arrival Agent.

Message#	Predicate	Parameters
H25	piece_received	id_piece, state
H26	transport_update	id_piece, info_update

example, when the hospital receives the wrong piece or the received piece is defectuous).

Finally the *Consultation Agent*, which is the interface with the Institution's database, processes the different types of queries sent by the *Surgeon Agent*, the *Planner Agent* or the *Coordinator Agent*. This is done, as Finder Agents do, by going to the *Carrel* institution. As the *Carrel* consultation procedures also follow the role-based access model, different levels of privilege are defined by the *Carrel* institution to restrict the access

to its database, so, for instance, queries created in the *Coordinator Agent* have a higher privilege level than the ones created inside the *Surgeon Agent* or the *Planner Agent*, and having a higher privilege level means having access to a wider amount of information in the Institution's database. The *Consultation Agent* has to cope with this privileged levels and the possible rejection of all or part of the information requested.

## 2.2. The Envelope

The information required by the *Finder Agent* to look for a piece in the *Carrel* is packed in an electronic *Sealed Envelope*. This envelope is created by the *Coordinator Agent* after it has received a valid piece request from the *Surgeon Agent*. The envelope contains the following information:

Table 15. Messages Coordinator Agent → Surgeon Agent.

Message#	Predicate	Parameters
H27	piece_assigned	id_request, (piece_info, delivery_plan)   none
H28	piece_problem_to_solve	id_request, info_problem
H29	inform_surgeon	priority_level, information

Table 16. Messages Coordinator Agent → Staff Agent.

Message#	Predicate	Parameters
H30	inform_staff	priority_level, information

Table 17. Messages Staff Agent → Coordinator Agent.

Message#	Predicate	Parameters
H31	inform_coordinator	priority_level, information

- *Urgency level*, that works as electronic postage stamp and sets the urgency level of the request (in Spain: normal, urgency-1 or urgency-0)
- *Hospital identification*, together with the *coordinator's electronic signature*. This electronic signature is an electronic certificate issued by the Certification Authority associated to the *Carrel* institution [2], and allows that institution to authenticate each request sender to make sure that only *Finder Agents* with requests from authorized senders can enter and negotiate inside *Carrel*.
- *Piece information* (type, parameters, etc.) and *recipient data* (age, sex, laboratory analysis, etc.).
- The *selection function*, as explained in Section 3.1.

The data needed by the *Coordinator Agent* in order to create this envelope comes from different sources that may be geographically distributed. The hospital identification and the electronic signature are issued by *Carrel* and only known by the *Coordinator Agent*. All the medical data about the piece and recipient are provided by the *Surgeon Agent* and the *Analyzer Agent*. An important constraint to be considered is the expected date for the transplant.

The format of an sealed envelope containing all the required information is the following:

```
<uctx-request>
  <hospital>HHH</hospital>
```

```
<urgency>0|1</urgency>
<timedeliver>TTTT</timedeliver>
<piece-type>PPPPP</piece-type>
<piece-info>...</piece-info>
<recipient-info>...</recipient-info>
</uctx-request>
```

### An UCTx Request Envelope

HHH stands for hospital identification code (which is provided by *Carrel*), *urgency* = 0 means delivery in less than 24 hours, and TTTT is the maximum date the recipient can wait to receive the piece (if applicable). PPPPP is the desired piece identification code. The *<recipient-info>* tag has associated the recipient's relevant information, and the *<piece-info>* tag contains the public relevant information of the piece selected (which is used by the *Finder Agent* jointly with the Selection Function (see Section 3.1), which is private information, in order to choose the piece. The envelope is delivered with the Hospital Transplant Coordinator's electronic signature.

The information required to create the selection function comes in part from the *Surgeon Agent*, reflecting the surgeon's preferences for the piece to get, and in part from the *Coordinator Agent*, reflecting the coordinator or hospital's preferences (such as costs, preferred Tissue Banks, etc.).

Once the envelope is created, it is delivered to the *Finder Agent*, which will send it to the *Institution* to look for the piece.

The envelope is an important piece of information that helps to protect the recipient's medical data and to improve and speed the assignment process. The envelope contains almost all the necessary information for the *Finder Agent* to perform its tasks.

### 3. An Example: The Cornea Transplantation

We will use the Cornea Transplantation process to illustrate our ideas. Unlike most tissues in the body, the

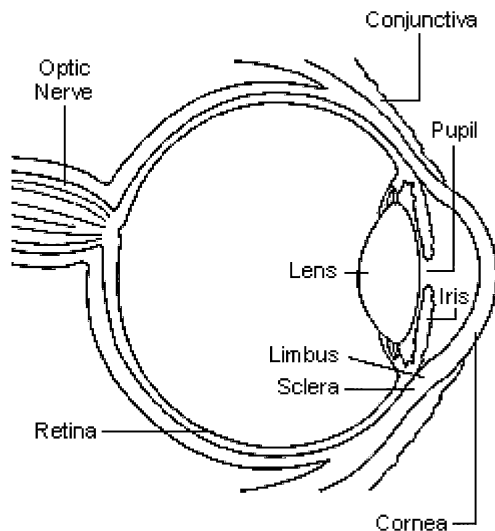


Figure 3. The eye.

cornea contains no blood vessels. The cornea must remain transparent to refract light properly, and the presence of even the tiniest blood vessels can interfere with this process. To see properly, all layers of the cornea must be free of any cloudy or opaque areas. The cornea is as smooth and clear as glass and it helps the eye in two ways:

- It helps to shield the rest of the eye from germs, dust, and other harmful matter. The cornea shares this protective task with the eyelids, the eye socket, tears, and the sclera (see Fig. 3).
- The cornea acts as the eye's outermost lens. It functions like a window that controls and focuses the entry of light into the eye. The cornea contributes between 65–75% of the eye's total focusing power.

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 Fig. 3), usually donated through a Tissue Bank (TB). A trephine is used to remove the damaged cornea. The surgeon places the new cornea in the opening and sews around it to connect it.

The need to automate part of the transplant coordination procedures can be seen if we take a look to the statistics show: in the United States over 40,000 cornea transplants are performed each year (in 1996 there were 46300, that is, 178 pmp)[24–26];<sup>5</sup> in Catalonia the number of transplants is increasing: in 1999,

845 cornea transplants were performed, that is, 141 pmp, and in 2000 there were 929 transplants, that is, 152 pmp [3]. So the number of transplants is growing so much that Human Transplant Coordinators are beginning to be overwhelmed by the requests.

The chances of success of this operation have also risen dramatically because of technological advances in the procurement, examination, preservation and implantation procedures and the improvement of the post-implant treatments. For instance, 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. In US, approximately 20% of corneal transplant patients—between 6000–8000 a year—reject their corneal grafts. The NEI-supported study, called the Collaborative Corneal Transplantation Study [27], also concluded that intensive steroid treatment after transplant surgery improves the chances for a successful transplant.

So the aim of the UCTx system is not only to automate an important part of the procedures but also allow faster and more exhaustive ways to find the proper cornea<sup>6</sup> for a given recipient, and also store data to monitor the whole process and to make further analysis of the results to detect any critical point in the procedures and then make the suitable improvements.

### 3.1. The Selection Function

Here we introduce the description of a *Selection Function*, one of the items that comprise the envelope's content the *Finder Agent* carries to the Institution with a request for a cornea. The *Selection Function* is a private piece of knowledge given by surgeons to guide the search for suitable corneas made by the *Finder Agent*.

The *Selection Function* is composed of a set of rules, each one a constraint the selected cornea has to satisfy. Some of these rules belong to the policy of the whole transplant unit of the hospital, 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* 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 Epithelial 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:

$$P_r = \{ (= Age_r\ Young) \wedge (= Blood\_Type_r\ A) \\ \wedge (= Sex_r\ Male) \wedge \dots \} \quad (3.1)$$

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 3.1 and the *Selection Function* shown in 3.2. This will be carried by the *Finder Agent* to the *Institution* [2].

$$(= Age_d\ Young) \wedge (= TB\ HSCSP) \\ \wedge (>EC_d\ 2000/mm^2) \quad (3.2)$$

where  $Age_d$  stands for the donor's age,  $TB$  stands for Tissue Bank (in the example, HSCSP is the bank of the Hospital de la Santa Creu i Sant Pau) and  $EC_d$  stands for the Endothelial Cells density in the donor's cornea. The definition of concepts like *Young* is settled by the Transplant Coordinator or by the Surgeons using an Ontology that is unique for each Hospital. Of course, each institution could specialize and customize its Selection Functions 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 constrains to some other more *acceptable*.

If we modify the recipient characteristics in 3.1 by doing ( $= Age_r\ Old$ ) then we can have the following Selection function:

$$(= TB\ HSCSP) \wedge (>EC_d\ 2000/mm^2) \quad (3)$$

which in turn is more *flexible* than 3.2.

As each kind of transplant procedure (Cornea Transplant, Lamellar Transplant, Keratoconus Transplant . . .) has different needs, there will be different rules for each one, and this means different selection functions. If we add to 3.1 the following information ( $=Transplant\ K$ ), where  $K$  stand for Keratoconus, then 3.2 will change to:

$$(= Age_d\ Young) \wedge (= TB\ HSCSP) \\ \wedge (>EC_d\ 2800/mm^2) \quad (4)$$

or even to

$$(= Age_d\ Young) \wedge (= TB\ HSCSP) \\ \wedge (>EC_d\ 2800/mm^2) \\ \wedge (= Erosion\_Ep_d\ False) \quad (5)$$

where  $Erosion\_Ep_d$  expresses whether there is erosion in the donor's Epithelial layer of the cornea. It is possible to specialize 3.2, 3, 4 and 5 by adding the following predicates

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

The *HLA* 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:

$$(= Age_r\ Young) \wedge (<Hours\_In\_TB\ 72) \quad (6)$$

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. This interface keeps all rules to be re-used in future requests. This rule base will constitute the *memory* of each service and should be exploited to learn better strategies to create new rules. The weights associated to rules allow the *Finder Agent* to know which of the rules are more important than others while it is searching for a cornea and, as it was introduced in

Section 2.1, the weights allow to qualify each piece and create a partial order among them.

### 3.2. Knowledge Representation

The Medical Knowledge domain is very large and vast amounts of information are available in very different formats, but this knowledge is often uncertain and vague. Another characteristic of this knowledge domain is that often it is incomplete and the sources of information are not always available in electronic format to allow evaluation processes.

Knowledge-based systems that support health care require large controlled terminologies to manage names and meanings of data elements. These terminologies are not static. To share data and applications in health care, we need standards and methods not only for terminologies and concept representation, but also for representing change [28]. This representation should be used in very different tasks as: (a) search for a term or piece, (b) retrieve information about a piece, a resource, etc., (c) translation to other coding schemes (i.e. between to hospitals), (d) uniform edition of the knowledge base.

As the basis of our Knowledge representation we are choosing to re-use previous efforts as GRAIL [5] or PROforma [23] and to use, at this stage, a very simple language to build rules as those of Section 3.1. In the near future we expect to improve the expressivity of this language.

## 4. Conclusions

The social pressure and the need to improve the quality of health care has led to a strong demand for clinical protocols and, lately, computer systems supporting both their creation and the execution. Organ and Tissue transplants in general, and corneal transplants in particular often are the best technique for the treatment of some major health problems that can affect the quality of life of an important part of the population. So improving the success of such techniques is very important.

In this work we propose the *UCTx* agency, a Multi-Agent System that models the interaction of the different actors of a Transplant Coordination Unit inside a Hospital. The *UCTx* system interacts with an Agent Mediated Institution for Human Tissue Exchange (see Carrel in [2]), and this collaboration ensures that the process meets the protocols and the rules established by

national transplant organizations and hospitals. *UCTx* speeds up the process by its automation, which can reduce the time since the extraction of the tissue to its implant in the recipient, increasing the quality of the piece implanted. That is of special relevance in the cornea's transplantation, as corneas are perishable. In other cases, the use of the systems will help in finding the *best* stored piece for a given patient.

The *UCTx* platform can be very helpful in a Transplant Coordination Unit as it can aid in some of the daily management issues such as coordination of surgeons or planning of operations and even automate some tedious tasks such as looking for an available surgery room or more specialized as looking for a proper tissue. It will help to maintain the medical data integrity and confidentiality by supervising every access to data and keeping track of any data demand, see for example [29]. This is coherent with the new Spanish law on personnel data protection [16, 18] and meets also the European Directive 97/66/CE on Data Protection [17].

*UCTx* can assist the surgeons while they build their requests for pieces (see Section 3), manage the requests and inform the Hospital Transplant Coordinator of any important event that occurs.

On the other hand, as the system asks for a complete clinical evaluation of each piece, it can decrease the cost of transplants by reducing the number of unsuitable transplants and furthermore offering a higher security level in reducing the chances of possible infections.

One additional advantage of using such a system is that the information that *UCTx* gathers about organs, tissues, bones and recipients is organized using an electronic format that can be analyzed later to obtain through data mining or machine learning procedures. Discovery of new knowledge by mining medical databases is crucial in order to make an effective use of stored data to generate new useful knowledge about the transplant process, knowledge which can lead to its improvement, from the enhancement of the tissue selection functions to the extraction and implantation procedures.

## Acknowledgments

We acknowledge the implementation efforts of Jorge Castillo (Carrel1), Jordi Angl  (Carrel2) and Marc Font (Carrel3). We would like to thank Dr. Julian Padget for his help in the inception of this article. At last but not the least we like to acknowledge the three anonymous reviewers that have provided us with very valuable

comments and constructive suggestions to enhance this paper.

This paper was supported in part by the EU research project *Advanced Training System for Emergency Management (A-TEAM)* IST-1999-10176.

## Notes

1. 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.
2. From now on we will use the word *pieces* to designate organs or tissues or bones.
3. JADE stands for Java Agent DEvelopment framework, a Java-based environment that follows the FIPA specifications for agent management, ACL message structure, communicative acts and interaction protocols.
4. Here we follow North's definition of an *Institution* as a collection of artificial constrains that shape human interaction [30].
5. pmp stands for per million of population.
6. We should note here that cornea transplants are only an example of use of the UCTx system, as it is obvious that a similar analysis can be done to use UCTx with other kind of tissues such as skin or bones.

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