UCTx: A Multi-Agent approach to model a Transplant Coordination Unit

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Abstract. We present an *Agency* called *UCTx* designed to model 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 an Agent Mediated Institution for the Exchange of Human Tissues among Hospitals for Transplantation. Also *UCTx* will act as the representative of the hospital in the transactions. As an example we present 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 attracted our attention following the work of López-Navidad *et al* [6], and we saw this unit as a good example of a multi-agent system that has to interact with others agents of different nature as for example: Surgeons, Agent Mediated Institution for the Exchange of Human Tissues among Hospitals for Transplantation such as *Carrel* [3], and organizations as the Organització Catalana de Transplantaments (OCATT) and the Organización Nacional de Transplantes (ONT) .

A related approach for monitoring medical protocols is described in [1].

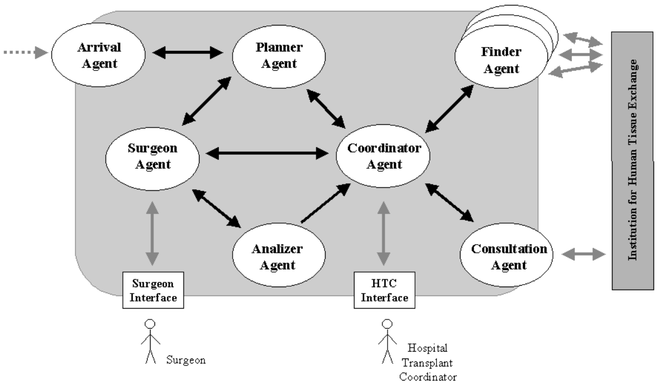

Fig. 1. The Transplant Coordination Unit's Agency

1.1 Organization of this paper

In section §2 we explain in detail the architecture of UCTx but we do not go into detail on the communication security issues.

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 in §3.1. Finally, in §4, we present some conclusions.

2 UCTx: The Transplant Coordination Agency

Our implementation has to reflect the infrastructure and staff of a real Transplant Coordination Unit (UCTx) which permits the successful conclusion of an organ or tissue[1] procurement and extraction process for transplantation [6]. In addition, it deals with the management of the requests for pieces made by the surgeons in order to transplant them into recipients.

It has in addition to observe the local, national and European Union legislation (see the reports of the ONT in [4] and the recommendations of the Transplant Experts Committee in [7]).

2.1 Description of the Agency

A UCTx is modeled as an Agency (see figure 1) that has several agents, each one competent in a specific task. The Agency is composed of a *Coordinator Agent*, *Surgeon*, *Analyzer*, *Finder*, *Planner*, *Consultation* and *Arrival* agents.

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

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

– Information confidentiality
– Information integrity
– Dynamic accessibility

The *Surgeon Agent*, specific for each kind of piece, is responsible of communicating with the human users (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 §3.1). This function provides a way to evaluate each piece for a given offer in the *Institution for Human Tissue Exchange*. The *Institution* assigns the pieces to the different competitor finder agents 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 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, and the *Hospital Transplant Coordinator* in person can communicate with this Agent through the *Coordinator Interface*. Afterwards, it creates 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* is also responsible to keep records of all the piece requests made by the hospital and to give feed-back to the *Institution* (see [3]) when the piece arrives, after transplantation and three weeks after the operation or in the case of any fatality.

The *Finder Agent* is provided with a sealed envelope with all the information required (ie. hospital information, patient's data, selection function, etc). When a *Finder Agent* returns from the *Institution for Human Tissue Exchange*, it communicates the result of the negotiation to the *Coordinator* (see message H7 in table 5). If a piece is found, the *Coordinator* 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, 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 for 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 send a message to the *Coordinator*. Otherwise, the *Surgeon Agent* can create its own proposal and can 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 *Arrival Agent* is responsible of informing 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. The *Planner* will be able to modify the delivery or the transplant plans dynamically.

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*. Different levels of privilege are defined by the institution to restrict the access to its database, so 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.

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

Table 1. Messages Surgeon Agent → Analyzer Agent

Message♯	**Predicate**	**Parameters**
H2	analysis_result	id_request, ok | (error, reason)

Table 2. Messages Analyzer Agent → Surgeon Agent

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

Table 3. Messages Analyzer Agent → Coordinator 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 4. Messages Coordinator Agent → Finder Agent

Message♯	**Predicate**	**Parameters**
H7	piece_assignation	id_request, (piece_info, delivery_plan) | none
H8	piece_problem_question	id_request, info_problem

Table 5. Messages Finder 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

Table 6. Messages Surgeon Agent → Coordinator Agent

Message♯	**Predicate**	**Parameters**
H13	query_request	id_query, info_request

Table 7. Messages Coordinator Agent → Consultation Agent

Message♯	**Predicate**	**Parameters**
H14	query_result	id_query, info_result

Table 8. Messages Consultation Agent → Coordinator Agent

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

Table 9. Messages Planner Agent → Surgeon Agent

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

Table 10. Messages Surgeon 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 11. Messages Coordinator Agent → Planner 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 12. Messages Planner Agent → Coordinator Agent

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

Table 13. Messages Arrival Agent → Planner Agent

2.2 The Envelope

The information required by the *Finder Agent* to look for a piece in the institution is stored in a *Sealed Envelope*. This envelope is created by the *Coordinator Agent* after it has received a piece request. The envelope contains the following 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*.
- *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 to create this envelope comes from different sources. The hospital identification and the electronic signature are known by the *Coordinator Agent*. All the 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 data for the transplant. 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.

3 An Example: The Cornea Transplantation

We will use the Cornea Transplantation process to illustrate our ideas. Unlike most tissues in the body, the 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 figure 2).
– 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 percent 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 figure 2), 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.

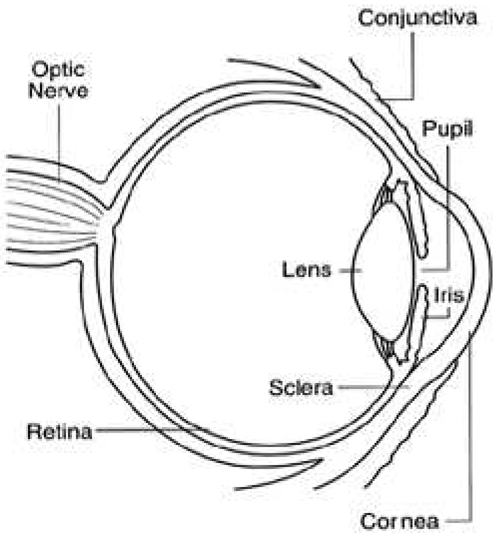

Fig. 2. The Eye

Corneal transplants are very common all over the world, the statistics show in the United States about 40,000 are performed each year, in 1996 there were 46300 that is 178 pmp [9], [2], [8]; in Catalonia, in 1999, there were 845 that is 141 pmp and in the first five months of 2000 there were already 185 transplants [10]. The chances of success of this operation have 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. Approximately 20 percent of corneal transplant patients–between 6000-8000 a year–reject their corneal grafts. The NEI-supported study, called the Collaborative Corneal Transplantation Study [5], 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.

3.1 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 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:

$$\begin{aligned} P_r \ = \ \{ \ (= \ Age_r \ Young) \wedge (= \ Blood\_Type_r \ A) \\ \wedge (= \ Sex_r \ Male) \wedge ...\} \end{aligned} \tag{3.1}$$

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* [3].

$$\begin{aligned} &(= \ Age_d \ Young) \wedge (= \ TB \ HSCSP) \\ &\wedge (> \ EC_d \ 2000/mm^2) \end{aligned} \tag{3.2}$$

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. 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 3.1 by doing $(=\ Age_r\ Old)$ then we can have the following Selection function:

$$(=\ TB\ HSCSP) \wedge (>\ EC_d\ 2000/mm^2) \tag{3.3}$$

which in turn is more *flexible* than 3.2.

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 3.1 the following information $(=\ Transplant\ K)$, where K stand for Keratoconus, then 3.2 will change to:

$$\begin{aligned}&(=\ Age_d\ \ Young) \wedge (=\ TB\ \ HSCSP)\\ &\wedge(>\ EC_d\ 2800/mm^2)\end{aligned} \tag{3.4}$$

or even to

$$\begin{aligned}&(=\ Age_d\ Young) \wedge (=\ TB\ HSCSP)\\ &\wedge(>\ EC_d\ 2800/mm^2)\\ &\wedge(=Erosion\_Ep_d\ False)\end{aligned} \tag{3.5}$$

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, 3.3, 3.4 and 3.5 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:

$$(=\ Age_r\ Young) \wedge (<\ Hours\_In\_TB\ 72) \tag{3.6}$$

as some surgeons think that corneas with more than 4 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, as it was introduced in section §2.1, the weights allow to qualify each piece.

4 Conclusions

Organ and Tissue transplants in general, and corneal transplants in special are often 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 system, 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 [3]), 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.

The UCTx system 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 a proper tissue or looking for an available surgery room. It can assist the surgeons while they build their requests for pieces (see §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 usitable transplants and furthermore offering a higher security level in reducing the chances of possible infections.

One additional advantage of such a system is that the information it gathers about tissues and recipients can be analyzed later to get new useful knowledge of transplantation, knowledge which can lead to an improvement of the transplant process, from the tissue selection functions to the extraction and implantation procedures.

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