Extending the Carrel System to mediate in the organ and tissue allocation processes: A first Approach.

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Abstract

In this paper we extend the formalization of Carrel, a virtual organization for the procurement of tissues for transplantation purposes, in order to model also the procurement of human organs for transplants. We will focus in the organ allocation process to show how it can be formalized with the ISLANDER formalism. Also we present a first mechanism to federate the institution in several geographically-distributed platforms.

1 Introduction

Organ transplantation from human donors is the only option available when there is a major damage or a malfunction in an organ. More than one million people in the world have successfully received an organ, being able the most of times to live again in normal conditions.

Over the years there has been an evolution in the transplantation techniques, an improvement in the knowledge about donor-recipient compatibility and an evolution in drugs for immunosuppression, allowing to increase the number of organs that can be implanted in a recipient and extending transplantation not only to organs (heart, liver, lungs, kidney, pancreas) but also to tissues (bones, skin, corneas, tendons). However, the allocation process is quite different for organs and tissues. These differences arise from the time such pieces can be preserved out of a human body. Tissues are clusters of quite homogeneous cells, so the optimal temperature for preservation of all the cells composing the tissue is almost the same. This makes that tissues can be preserved for several days (from six days in the case of corneas to years in the case of bones) in tissue banks. The allocation process is triggered when there is a recipient with a need for a certain tissue. For each recipient a search is done in all or some of the tissue banks looking for a suitable tissue

Organs are very complex structures with several kinds of cell types with different optimal preservation temperatures. That fact leads to quite short preservation times allowed (hours). So there is no time to store them in a bank. The allocation process is triggered when a donor appears, and the search is done in all or some hospitals for a suitable recipient.

1.1 The need of software systems for the organ and tissue management

As explained in [13], in the case of tissues success in transplantations is leading to an increase in the amount of requests for tissues that starts to overwhelm the human coordinators and leads to tissue losses in tissue banks (tissues that were available but were not assigned due to lack of time to process all requests).

In the case of organs, success in transplantations has also led to an increase in demand of organs for transplantation purposes. Unfortunately, there is not a volume of donations to match the demand. Lots of research has been done in order to create policies of donor identification (to increase the number of available donors), organ allocation (to find a suitable recipient for each organ) and in extraction, preservation and implant procedures (to increase the success probabilities).

The relative scarcity of donors has led to the creation of international coalitions of transplant organizations. This new, more geographically distributed, environment makes an even stronger case for the application of distributed software systems to solve:

- the data exchange problem: Exchange of information is one of the issues, as each of the actors uses to collect different information and store it in different formats. So an standard data interchange format has to be created to share information,

- the communication problem: Several countries use different languages and terminologies to tag the same items or facts. Either an standard notation or a translation mechanism needs to be created to avoid misunderstandings.

- the coordination issues: in order to manage requests at an international level, there is the need of coordinating surgery teams geographically distributed, and to coordinate delivery at an international level.

- the variety of regulations: an added issue is the necessity to accommodate a complex set of, in some cases conflicting, national and international regulations, legislation and protocols governing the exchange of organs. These regulations use to change in time, making impresdindible of easy-to-adapt software.

First two points are usually solved using standard software solutions. For instance, EU projects `RETRANSPLANT, TECN`) devote most of their work to the creation of a) standard formats to store and exchange information about pieces, donors and recipients among organizations, b) telematic networks, or c) distributed databases . Project `ESCULAPE` uses conventional software to help in matching tissue histocompatibility

The third point (coordination) is harder to solve with conventional software. A sound alternative is the use of *software agents*. An *Agent* is a computer program capable of taking its own decissions with no external control (*autonomy*), based on its perceptions of the environment and the objectives it aims to reach [14]. It not only reacts to the environment (*reactivity*) but also *proactivelly* takes initiatives. The *social ability* of agents allow them to group together (in *agencies*) sharing common objectives and dividing the tasks to reach those objectives. All these useful attributes make multi-agent systems well-suited for solving coordination issues.

It is the last point (variety of regulations changing in time) which underpins our case for the use of so-called *electronic institutions*, whose purpose is to provide overarching frameworks for interaction of agents capable of reasoning about the norms, in the same way as institutions, or equivalently, social norms, do in the physical world. That makes the system able to adapt automatically to changes in regulations.

In summary, our proposal covers all four points, using Multi-agent technology not only for the coordination and regulation issues but also serving as a language interface among teams using different terminology, and actively distributing the information to be shared.

2 An Institution for the distribution of organs and tissues

The Carrel System is an agent platform which behavior could be briefly described as an *agency* that receives a tissue request from one hospital and then tries to allocate the *best* tissue available in all the tissue banks that are known. In this agency different entities play different roles that are determined by their goals at each particular moment. Figure 1 depicts all the entities that interact with the Carrel system. There are a)the hospitals that create the tissue requests, b) the Tissue Banks, and c) the national organ transplantation organizations, that own the agent platform and act as observers -in the figure are depicted the organizations in Spain: the Organización Nacional de Trasplantes[1] (ONT) [11] and the Organitzaciò CATalana de Transplantaments[2] (OCATT)-. In the proposed system all hospitals, even those owning a Tissue Bank, should make their requests through Carrel in order to ensure a fair distribution of pieces and to ease the tracking of all pieces from the extraction to the transplantation, as the ONT and OCATT require for organs.

The role of the Carrel Institution can be summarized in the following tasks:

- it has to make sure that all the agents which enter into the institution behave properly (that is, that they follow the behavioral norms).
- it has to be updated of all the available pieces in the Tissue Banks.
- it has to check that all hospitals and tissue banks fulfill all the requirements needed to interact with Carrel.

[1] National Transplant Organization
[2] Catalan Transplant Organization

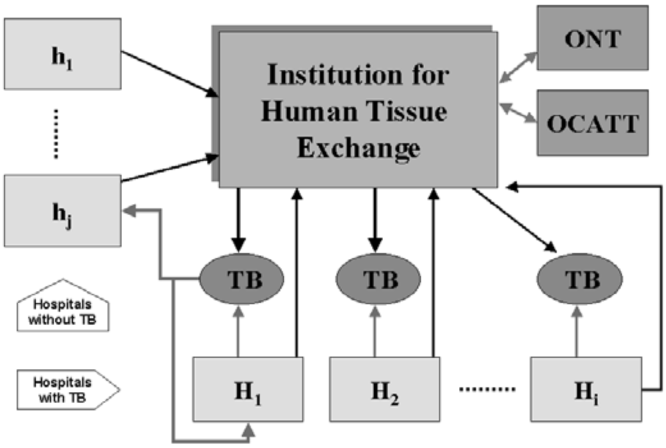

Figure 1: Carrel: An Agent Mediated Institution for Tissues Assignment

- to take care of the fulfillment of the commitments done inside the Carrel system.
- to coordinate the piece delivery from tissue banks to hospitals
- to register all incidences related to a certain piece.

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. A Hospital is represented in Carrel by the Transplant Coordination Unit Agency (*UCTx*). This agency (depicted in figure 14) serves as interface between the surgeons and Carrel. When a surgeon needs a piece he 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.

The information required by the *Finder Agent* to look for a piece in *Carrel* is packed in an electronic *Sealed Envelope*. 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*, an certificate issued by the Certification Authority associated to the Carrel institution [2], to allow the institution to authenticate each request sender in order to make sure that only *Finder Agents* with requests from authorized hospitals can enter and negotiate inside Carrel.
- *Tissue information* (type, parameters, etc.) and *recipient data* (age, sex, laboratory analysis, etc.).

- The *selection function*.

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 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 contain:

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

2.1 Extending the Carrel institution

In order to extend the Carrel System presented in [13] to cope with organ distribution, the organ allocation process should be modelled. In most of the official organ allocation organizations, the process is composed of two phases:

1. Each hospital informs to the organization about patients that have been added or removed in the waiting list of that hospital, or patients to be either added to or removed from the national-wide Maximum Urgency Level [3] Waiting List.
2. When a donor appears, the hospital informs of all the organs suitable for donation in the form of *offers* sent to the organ allocation organization, who assigns the organs.

This process can be formally modelled by modelling the interaction of agents. To give a formal description of the interaction among agents in the Carrel system we will follow the same formalism used for the case of tissues [13]. The ISLANDER formalism [4] views an agent-based electronic institution as a type of *dialogical system* where all the interactions inside the institution are a composition of multiple dialogic activities (message exchanges). These interactions (called *illocutions* [10]) are structured through agent group meetings called *scenes* that follow well-defined protocols.

Instead of creating a separate model for the organ allocation process, we will extend the model for the tissue allocation process. Some of the scenes that were defined for the case of tissues will be shared for organs by extending their functionalities, and some new scenes are created. The resulting set of scenes is the following.

[3] In Spain the Maximum Urgency Level is called Urgency-0

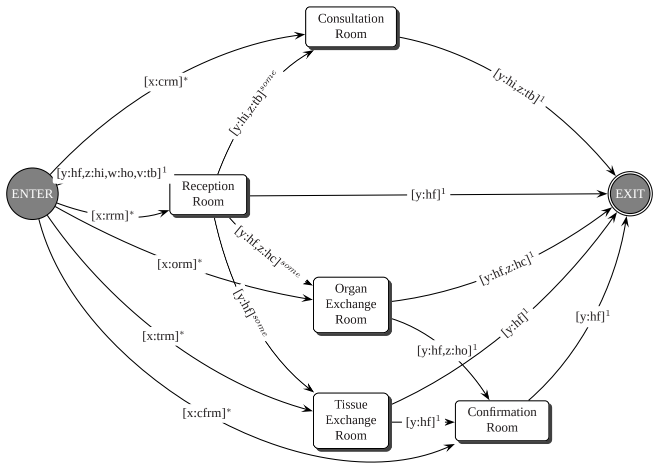

Figure 2: The Carrel Institution performative structure

- *Reception Room*: is the scene where all the external agents should identify themselves in order to get assigned with the roles they are authorized to play. If these agents are carrying either a request for one or more tissues or an offer of one or more organs, then this information is checked to make sure that it is well-formed.

- *Consultation Room*: is the scene where the institution is updated about any event or incident related to a piece. Agents coming from Tissue banks should keep updated the institution about tissue availability, while agents coming from hospitals should keep updated the institution about the waiting lists and also inform about the reception of all pieces (organs or tissues) they have received, the transplantation and the evolution of all the recipients.

- *Exchange Room*: is the scene where the assignation process is made. There would exist, in fact, specific exchange rooms for managing tissue requests (*Tissue Exchange Room*) and others to manage organ offers (*Organ Exchange Room*).

- *Confirmation Room*: scene where the provisional assignments made in either a *Tissue Exchange Room* or a *Organ Exchange Room* are confirmed or cancelled because of the arrival of another request with higher priority. In case of the confirmed ones, a delivery plan is built.

Another key element of the ISLANDER formalism is the definition of agent *roles*. Each agent can be associated to one or more roles, and these roles define the scenes the agent can enter and the protocols it should follow (the *scene protocols* are defined as multi-role conversational patterns). There are two kinds of roles: the *external roles* (roles for incoming agents) and the *institutional roles* (roles for agents that carry out the management of the institution). The external roles are the following:

***Hospital Finder Agent* (hf):** agents sent by hospitals with tissue requests or organ offers that are seen from the point of view of the institution as requests for finding an acceptable tissue or receptor, respectively.

***Hospital Contact Agent* (hc):** agents from a certain hospital that are contacted by the institution when an organ has appeared for a recipient that is in the waiting list of that hospital. The agent enters then into the institution to accept the organ and to receive the delivery plan.

***Hospital Information Agent* (hi):** agents sent by hospitals to keep the Carrel system updated about any event related to a piece or the state of the waiting lists. They can also perform queries on the Carrel database.

***Tissue bank notifier* (tb):** agents sent by tissue banks in order to update Carrel about tissue availability.

The institutional roles consist of one agent to manage each scene and one agent to coordinate all the scene relationships:

***Institution Manager* (im):** the agent coordinating all the scene managers.

***Reception Room Manager* (rrm):** the manager of the *Reception Room* scene.

***Tissue Exchange Room Manager* (trm):** the manager of a *Tissue Exchange Room* scene.

***Organ Exchange Room Manager* (orm):** the manager of a *Organ Exchange Room* scene.

***Confirmation Room Manager* (cfrm):** the manager of the *Confirmation Room* scene.

***Consultation Room Manager* (crm):** the manager of the *Consultation Room* scene.

2.2 The performative structure

The connection among scenes constitutes the *performative structure*. It is a network of scenes that defines the possible paths for each agent role. In accordance with its role, an agent may or may not be permitted to follow a particular path through the performative structure, and ultimately, may be required to leave the institution.

With all the scenes and roles identified in the previous section, the performative structure (a graph that defines the allowed paths among scenes for each agent according to their roles) can be drawn, as depicted in figure 2. Nodes are the scenes listed above plus an *enter* and *exit* nodes in order to define a begin and end points in the diagram. Arcs are labelled with tags *variable:role*, where variable is an agent$_i$ and role is one among the identified roles for the Carrel system. The diagram in figure 2 shows, for instance, that scene's managers go directly from the *enter* point to the scene they should manage (the * means that they are the ones creating the scene), while all the external agents must proceed through the *Reception Room* scene in order to be registered and then be directed to the proper scene according to their roles.

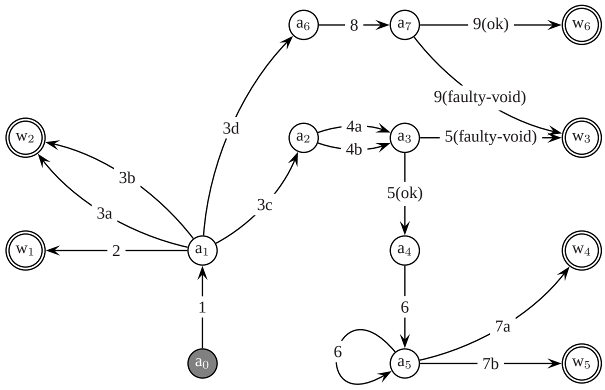

Figure 3: The conversation graph for the Reception room

Msg♯	Illocution
1	(request (?x hf|hc|tb) (?y rrm) (admission ?id_agent ?role ?hospital_certificate))
2	(deny (!y rrm) (!x hf|hc|tb) (deny ?deny_reason))
3a	(accept (!y rrm) (!x hc) (accept_hc))
3b	(accept (!y rrm) (!x tb) (accept_tb))
3c	(accept (!y rrm) (!x hf) (accept_hf))
3d	(accept (!y rrm) (!x ho) (accept_ho))
4a	(inform (?x hf) (?y rrm) (petition_tissue ?id_hospital ?urgency_level ?time_to_deliver ?piece_type (?piece_parameters) (?info_recipient)))
4b	(inform (?x hf) (?y rrm) (petition_organ ?id_hospital ?time_for_availability ?piece_type (?piece_parameters) (?info_donor)))
5	(inform (!y rrm) (!x hf) (petition_state ?id_petition ok|faulty))
6	(inform (?y rrm) (?x hf) (init_exchange ?piece_type ?id_exchange_room))
7a	(request (?x hf) (?y rrm) (tissue_exchange_entrance_request !id_exchange_room))
7b	(request (?x hf) (?y rrm) (organ_exchange_entrance_request !id_exchange_room))
8	(inform (?x ho) (?y rrm) (called_for_organ ?id_hospital !id_petition)
9	(inform (!y rrm) (!x hf) (called_state !id_petition ok|faulty))

Figure 4: The illocutions for the Reception room

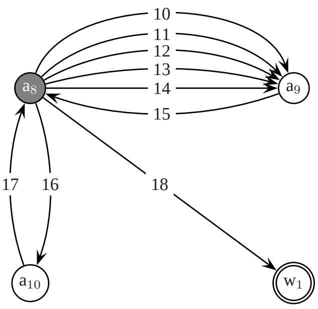

Figure 5: Conversation graph for the Consultation room

Msg♯	Illocution
10	`(inform (?x hc) (?y crm) (piece_arrival ?id_hospital ?id_tissue_bank ?id_piece (?state)))`
11	`(inform (?x hc) (?y crm) (transplantation_eval ?id_piece ?id_recipient ?date (?info_transplantation)))`
12	`(inform (?x tb) (?y crm) (tissue_bank_update ?id_tissue_bank ?id_piece (?specifications)))`
13	`(inform (?x hc) (?y crm) (waiting_list_update ?id_hospital ?id_piece ?id_recipient ?time_in (?info_recipient) ))`
14	`(inform (?x hc) (?y crm) (maximum_urgency_level_update ?id_hospital ?id_piece ?id_recipient ?urgency_level ?time_in (?info_recipient) ))`
15	`(inform (!y crm) (!x hc|tb) (notification_ack !id_piece ok|error))`
16	`(query-if (?x hc) (?y crm) (?query))`
17	`(inform (!y crm) (!x hc) (query_results (?results))`
18	`(request (?x hc|tb) (?y im) (end))`

Figure 6: Illocutions for the Consultation room

2.2.1 Authentication of external agents

As explained above, in the *Reception Room* external agents enter and are registered inside the platform. In this room an authentication mechanism based in electronic certificates ensures that external agents come only from authorized organizations (which previously received the electronic certificate to be used). Once the sender has been identified and authorized, the external agents are then headed to the proper room according to their roles.

The protocol of this scene can be seen in figure 4: An agent$_i$ makes a request for admission (1) that can be accepted (messages 3a, 3b, 3c, 3d) or refused (message 2, exit state w_1). According to the role of the incoming agent$_i$:

- it is headed to the *Consultation Room* (exit state w_2),

- if it brings a request from a hospital, a checking of such request is done (messages 4 and 5). Then agent$_i$ waits until a proper *Exchange Room* is available to do the assignation (messages 6 and 7a for tissues, 6 and 7b for organs).
- if it was called by the institution to receive an organ offer, the information it brings about the recipient is checked and, if all is correct, then is headed to the *Organ Exchange Room* that sent the call.

2.2.2 Registering the recipients and the available pieces

In order to manage the assignation of organs and tissues, the Carrel institution should be updated of a) all the available tissues for transplantation, b) the state of hospitals waiting list for each kind of organ, and c) the whereabouts about all pieces that have been assigned by Carrel.

The *Consultation Room* allows agents coming from hospitals or tissue banks to keep Carrel updated about all the facts mentioned above. The protocol of this scene is shown in figure 6. The incoming agents can perform notifications (messages 10 to 14) and are informed if the notification is successful (message 15). The agents coming from hospitals —which represent the Hospital Transplant Coordinator [3]— can also perform queries (message 16) about historical facts (e.g. statistics on, say, successful cornea transplantations over a certain period). The queries are answered (message 17) with the level of detail that is permitted for a certain role, as all access to the database is controlled through a *Role-Based Access Model* [7]. When the incoming agents have performed all the queries and notifications, they exit the Carrel system (message 18).

2.2.3 Allocating organs

In order to do the organ assignation, a new scene, the *Organ Exchange Room* has been added. The protocol of this scene, depicted in figure 8, can be divided in two parts:

- the arrival of an Agent$_i$ (hospital *Finder Agent*) with an offer of an available organ (states a_{11} and a_{12}), waiting for a notification that a proper recipient has been found (message 22, exit state w_3) or not (message 27 leading to a request for exit through state w_1).
- the loop of the scene manager looking for recipients. Based in the information of the waiting lists stored in Carrel's database, the scene manager sends a call to a hospital (message 20) where there's a proper recipient. Then an Agent$_j$ (hospital *Contact Agent*) enters into the scene to answer the call, telling if it accepts the organ or not (message 20). Sometimes Agent$_j$, representing the hospital Transplant Coordinator, expresses the intention to use the organ in a different recipient (message 23), change that depending on the reasons given can be either accepted or rejected (messages 24 and 25). If the scene manager and Agent$_j$ get an agreement, then Agent$_i$ is notified about the recipient, otherwise Agent$_j$ exits the scene and the loop starts again with a call to other hospital for another recipient, if exists.

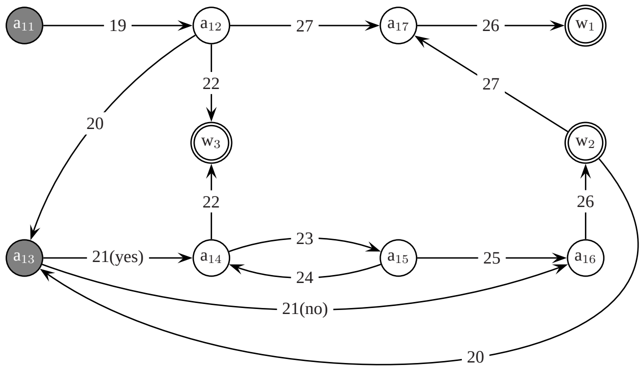

Figure 7: The conversation graph for the Organ Exchange room

Msg♯	Illocution
19	`(query-if (?x hf) (?y orm) (recipient_for_organ ?id_petition))`
20	`(query-if (?x orm) (?y hc) (call_for_recipient ?id_recipient !id_petition ?time_for_availability ?piece_type (?piece_parameters) (?info_donor)))`
21	`(inform (!y hc) (!x orm) (call_answer !id_petition ?id_hospital))`
22	`(inform (?x orm) (?y hf) (recipient_found !id_petition !id_recipient !id_hospital))`
23	`(query-if (?x hc) (?y orm) (change_recipient (!id_previous_recipient ?id_new_recipient ?change_reason))`
24	`(inform (!y orm) (!x hc) (accept_change))`
25	`(inform (!y orm) (!x hc) (reject_change reason))`
26	`(request (?x hf|hc) (y im) (exit ?exit_reason))`
27	`(inform (?x orm) (?y hf) (recipient_not_found reason))`

Figure 8: The illocutions for the Organ Exchange Room

The search and assignation processes made by the scene manager are driven by the knowledge about donor-recipient compatibility that is coded in the form of rules like the following:

```
1- (age_donor <= 1)
     -> (age_recipient < 2)

2- (age_donor > 1) AND (age_donor < 4)
     -> (age_recipient < 4)

3- (age_donor >= 4) AND (age_donor < 12)
     -> (age_recipient > 4) AND (age_recipient < 60)

4- (age_donor >= 12) AND (age_donor < 60)
     -> (age_recipient >= 12) AND (age_recipient < 60)
```

```
5- (age_donor >= 60) AND (glomerulosis <= 15%) AND
   (age_donor < 74)
     -> (age_recipient >= 60) AND
        (transplant_type SINGLE-KIDNEY)

6- (age_donor >= 60) AND (glomerulosis > 15%) AND
   (glomerulosis <= 30%)
     -> (age_recipient >= 60) AND
        (transplant_type BOTH-KIDNEYS)


7- (weight_donor = X)
     -> (weight_recipient > X*0.8) AND
        (weight_recipient < X*1.2)


8- (disease_donor Hepatitis_A)
     -> (disease_recipient Hepatitis_A)

9- (disease_donor Hepatitis_B)
     -> (disease_recipient Hepatitis_A)

10-(disease_donor Hepatitis_C)
     -> (disease_recipient Hepatitis_A)


11-(disease_donor VIH)
     -> (DISCARD-ORGAN)

12-(glomerulosis > 30%)
     -> (DISCARD-ORGAN)
```

Rules 1 to 7 are related to size compatibility, either considering age ranges (rules 1 to 6) or weight differences over a 20% in the decission making. Rules 5 and 6 also consider quality of the kidney (the glomerulosis is a negative factor in kidneys filtering behaviour) and assess not only the limit that is acceptable but also the transplant technique to be used (to transplant one or both kidneys). Rules 8 to 10 are examples of diseases in the donor tha do not lead to discarding the organ for transplantation, if a proper recipient is found (in the example, a recipient that has had also the same kind of Hepatitis in the past). Finally, rules 11 to 12 are examples of rules for rejecting organs for transplantation, as told by the current medical knowledge.

It is important to not implement this policies hard-coded in the system, as this kind of rules use to change while praxis evolves (for instance, some years ago donors with some kind of Hepatitis were discarded). Expresing the knowledge in the form of rules allows the system to adapt to future changes in medical praxis.

2.2.4 Allocating tissues

The *Tissue Exchange Room* is the place where negotiation over tissues is performed. The protocol of this scene is shown in figure 10: Agent$_i$ (hospital *Finder Agent*) asks the scene manager for tissue offers (tissues matching the requirements included in their petition). Then the scene manager gives a list of available tissues (message 29) that is evaluated by the external agent$_i$ (message 30). With this information the scene manager can make a provisional assignment and solve collisions (two agents interested in the

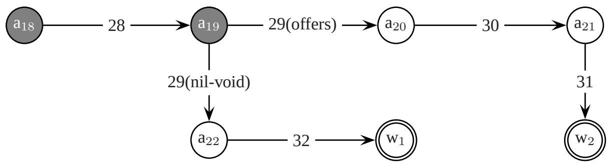

Figure 9: The conversation graph for the Tissue Exchange room

Msg♯	Illocution
28	`(query-if (?x hf) (?y trm)(offer_list ?id_petition))`
29	`(inform (!y trm) (!x hf) (offer_list !id_petition (list (?id_piece1 ?info_piece1) ... (?id_piecen ?info_piecen)))`
30	`(inform (?x hf) (?y trm) (weighted_list !id_petition (list (!id_piece1 ?weight) ... (!id_piece1 ?weight)))`
31	`(query-if (?y trm) (?x hf) (piece_offer (?id_petition ?id_piece ?cost_estimation)|void))`
32	`(request (?x hf) (y im) (exit ?exit_reason))`

Figure 10: The illocutions for the Tissue Exchange Room

same tissue). When this provisional assignment is delivered (message 31) then agent$_i$ exits the scene to go to the *Confirmation Room* represented by state w_2. There is an alternative path for the case when there are no available pieces matching the requirements described in the petition (message 9 with null list). In this case agent$_i$ requests an exit permission from the institution (message 32, exit state w_1), including the reason for leaving. The reason provided is recorded in the institution logs to form an audit trail for the relevant authorities to inspect. For further information about this negotiation process see [2].

2.2.5 Confirming the assignation

In the *Confirmation Room* scene, the provisional assignments made in a *Tissue Exchange Room* or an *Organ Exchange Room* are either confirmed or withdrawn. Figure 12 shows the protocol of this scene: the agent$_i$ can analyze the assigned piece data and then accept or refuse it (message 33). If the agent$_i$ accepts the piece and no higher-priority requests appear during a certain time window then the provisional assignment is confirmed and a delivery plan is given to the agent$_i$ (message 34), and then it exits the Carrel system (exit state w_2). When there is a request with higher priority that needs the piece provisionally assigned to agent$_i$ a conflict arises. To resolve the conflict the scene manager notifies the agent$_i$ that the assignment has been withdrawn (message 35) and that he is then entitled to a fresh request for another piece, if available, (message 36) to be negotiated again in the *Exchange Room* where it came.

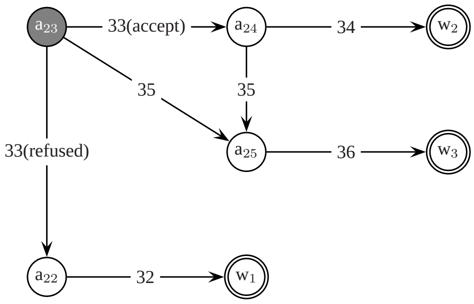

Figure 11: Conversation graph for the Confirmation room

Msg♯	Illocution
32	`(request (?x hf) (y im) (exit ?exit_reason)`
33	`(inform (?x hf) (?y cfrm) (piece_eval ?id_petition ?id_piece accepted|refused))`
34	`(inform (?y cfrm) (?x hf) (piece_delivery ?id_petition ?id_hospital ?id_tissue_bank ?delivery_plan))`
35	`(inform (?y cfrm) (?x hf) (piece_reassigned_exception ?id_petition ?id_piece ?reassignment_reason))`
36	`(query-if (?x hf) (?y cfrm) (another_offer_list ?id_petition))`

Figure 12: Illocutions for the Confirmation room

2.2.6 The Multi-agent architecture

The agent architecture that performs the *institutional roles* is shown in figure 13. There is one agent managing each of the scenes: the **RM Agent** managing the *Reception Room*, the **CR Agent** managing the *Consultation Room*, an **ER Agent** for each *Exchange Room* (either the ones for organs or the ones for tissues), and a **CfR Agent** managing the *Confirmation Room*. Also there's an agent (the **IM Agent**) playing the *institution manager* role.

In order to assist those agents, two agents are added for specific tasks: the **Planner Agent**, to build the delivery plans that are needed in the *Confirmation Room*, and the **DB Agent**, which is devoted to the access control of the internal Database.

2.3 Extending the UCTx

Adapting the UCTx agency in order to assist not only in the tissue allocation process but also in the organ allocation process is not difficult. While in the case of tissues, where surgeons are the ones responsible for creating the tissue requests through their **Surgeon Agent** [3], in the case of organs is the *Hospital Transplant Coordinator* the one responsible for issuing organ offers to the institution or answering a call for recip-

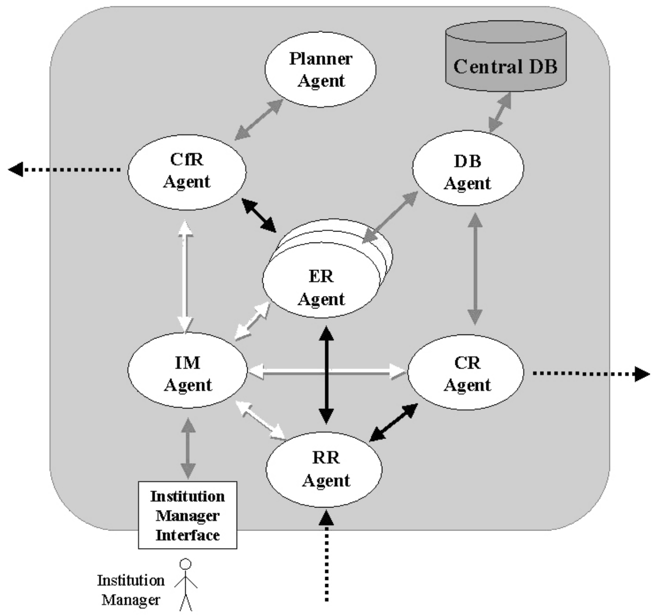

Figure 13: The multi-agent architecture of a Carrel platform

ients. So the architecture presented in [3] (depicted in figure 14) is not modified but only the **Coordinator Agent** functionalities, that are extended.

2.4 Distributing the Carrel institution

In the previous sections the Carrel system has been described as an institution that works alone, managing all the requests and offers coming from the hospitals. However some kind of distribution of the system is needed in order to manage the allocation problem at an international level (one of the aims of our proposal).

To do so, we propose to create a federation of geographically-distributed Carrel platforms. Hospitals and Tissue banks register themselves to the ”nearest” platform and interact as described in previous sections.

It is the search process the one distributed: the platforms exchange information among themselves through their **DB Agents**. The process is the following:

- The **DB Agent** of a certain platform$_i$ receives a query, either from an *Organ Exchange Room*, a *Tissue Exchange Room* or the *Consultation Room*
- It accesses the local Database.
- If the information is not available locally, then it sends part of the query to other **DB Agents** in the other Carrel Platforms.

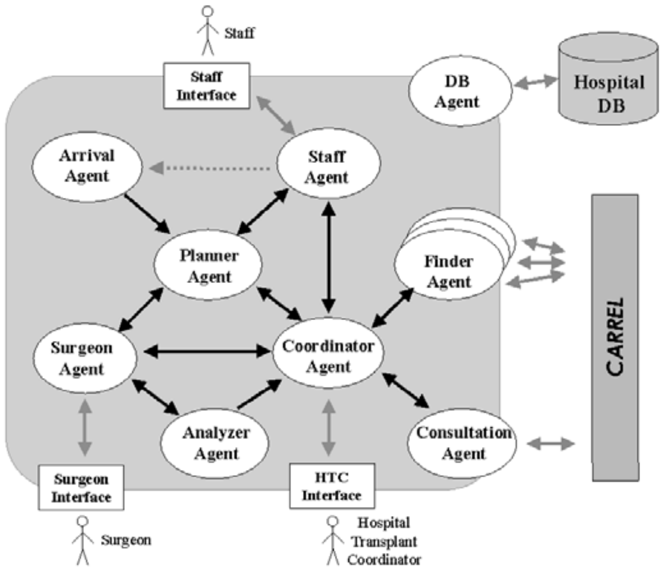

Figure 14: The multi-agent architecture for the UCTx system

- All the diferences in notation are solved at this point by the use of domain ontologies shared by all the platforms that define a common exchange format for the information.

All Carrel platforms are aware of the existence of the other platforms. The communication among agents of different platforms is done through the mechanism the FIPA specification stablishes for communication among Agent platforms [5].

3 CONCLUSION

We present here an Agent-Mediated Electronic Institution for the distribution of organs and tissues for transplantation purposes. Our aim with this work is not only to apply multi-agent technologies to model the organ and tissue allocation problem but we also have devoted part of our efforts in formalization, following the recommendations in [6] about the need of formal design methods when applying agents to the medical domain in order to ensure the *safety* and *soundness* of the resulting system. In our case we have chosen a formalism called ISLANDER [4], based on the dialogical framework idea, to get an accurate description of the interactions among the agents. By means of such formalism we have been able to desing a system that joins the strengths of agents with the adventages of formal specifications.

As far as we know, there are very few references in the literature about the use of agents in the transplant domain. [12] and [9] describe single agents to solve specific tasks needed for this domain (respectivelly, a receiver selection algorithm based in multi-criteria decision techniques and a planner of transport routes among hospitals for organ delivery). [8] proposes a multi-agent system architecture to coordinate all the hospital members involved in a transplant. And [1] proposes a static hierarchical agent architecture for the organ allocation problem, but no formalism is used in the development of the architecture, and no mechanism is presented to make the architecture adaptive to changes in policies or regulations.

Future work aims to explore other alternative formalisms to describe multi-agent systems in complex domains. As part of that exploration we aim to expand the PRO$forma$ [6] formalism, which is well-suited to model decission support systems for domains with uncertainty, to include agent communication and the definition of multiple roles (in the sense that each role has a different view of the problem to solve).

References

[1] A. Aldea, B. López, A. Moreno, D. Riaño, and A. Valls, 'A multi-agent system for organ transplant co-ordination.', in *Proceedings of the 8th. European Conference on Artificial Intelligence in Medicine, Portugal, 2001.*, eds., Barahona Quaglini and Andreassen (Eds.), Lecture Notes in Artificial Intelligence 2101: Artificial Intelligence in Medicine, pp. 413–416., (2001).

[2] U. Cortés, A. López-Navidad, J. Vázquez-Salceda, A. Vázquez, D. Busquets, M. Nicolás, S. Lopes, F. Vázquez, and F. Caballero, 'Carrel: An agent mediated institution for the exchange of human tissues among hospitals for transplantation', in *3er Congrés Català d'Intel.ligencia Artificial*, pp. 15–22. ACIA, (2000).

[3] U. Cortés, J. Vázquez-Salceda, A. López-Navidad, and F. Caballero, 'UCTx: A multi-agent system to assist a transplant coordinator unit', *Applied Intelligence. Accepted*, (2002).

[4] Marc Esteva, Julian Padget, and Carles Sierra, 'Formalizing a language for institutions and norms', in *Intelligent Agents VIII*, eds., Milinde Tambe and Jean-Jules Meyer, Lecture Notes in Artificial Intelligence. Springer Verlag, (2001). to appear.

[5] The Foundation for Intelligent Phisical Agents, http://www.fipa.org/repository/fipa2000.html, *FIPA Specifications*, 2000.

[6] J. Fox and S. Das, *Safe and Sound*, MIT Press, 1st edn., 1999.

[7] A. Lin, 'Integrating policy-driven role-based access control with common data secutiry architecture', Technical Report HPL-1999-59, HP Laboratories Bristol, (1999).

[8] A. Moreno, A. Valls, and J. Bocio, 'Management of hospital teams for organ transplants using multi-agent systems.', in *Proceedings of the 8th. European Conference on Artificial Intelligence in Medicine, Portugal, 2001.*, eds., Barahona Quaglini and Andreassen (Eds.), Lecture Notes in Artificial Intelligence 2101: Artificial Intelligence in Medicine, pp. 374–383., (2001).

[9] A. Moreno, A. Valls, and A. Ribes, ‘Finding efficient organ transport routes using multi-agent systems.’, in *IEEE 3rd International Workshop on Enterprise Networking and Computing in Health Care Industry (Healtcom), L’Aquilla, Italy.*, (2001.).

[10] P. Noriega, *Agent-Mediated Auctions: The Fishmarket Metaphor*, number 8 in IIIA Monograph Series, Institut d’Investigació en Intel.ligència Artificial (IIIA), 1997. PhD Thesis.

[11] Organización Nacional de Transplantes. http://www.msc.es/ont.

[12] A. Valls, A. Moreno, and D. Sánchez, ‘A multi-criteria decision aid agent applied to the selection of the best receiver in a transplant.’, in *4th. International Conference on Enterprise Information Systems, Ciudad Real, Spain.*, (2002).

[13] J. Vázquez-Salceda, U. Cortés, and J. Padget, ‘Formalizing an electronic institution for the distribution of human tissues’, in *Artificial Intelligence in Medicine*, (to be published).

[14] M. Wooldrige and N.R. Jennings, ‘Intelligent agents: Theory and practice’, *The Knowledge Engineering Review*, **10**(2), 115–152, (1995).