Extending CARREL's Architecture for Agents to Argue over the Viability of a Human Organ

P. Tolchinsky, U. Cortés, J.C. Nieves and J. Vázquez-Salceda
Universitat Politècnica de Catalunya

Abstract

In this report we present an extension to CARREL's architecture. CARREL is an agent-based organization designed to improve the overall transplant process. The proposed extension will enable CARREL agents to reason and deliberate over the viability of a human organ for transplantation. We believe that allowing this deliberation has the potential to augment the organ pool for transplantation and thus, reduce the disparity between demand for, and supply of, human organs for transplantation.

1 introduction

Human organ transplantation constitutes the only effective therapy for many life-threatening diseases. However, while the increasing success of transplants has led to increase in demand, the lack of a concomitant increase in donor organ availability has led to a growing disparity between supply and demand. Hence, much research has focussed on definition and implementation of policies for increasing donor availability, identification of suitable recipients for organs, and procedures to increase the chances of successful transplantation. As a consequence of the success of transplantation and the increase in the demand for transplant operations, the human transplant coordinators are currently facing significant problems in dealing with the volume of work involved in the management of requests, assignation and distribution of tissues and organs. Given the constant progress in transplant-based therapies and the relative success of these therapies, the demand for organs and tissues is expected to raise even more. A review of the coordinator's role and the difficulties faced is presented in [9]. Moreover, there is an increasing requirement for managing and processing vast and complex data, and accommodation of a complex set of, in some cases conflicting, national and international regulations and protocols governing exchange of organs and tissues. Hence, in [15] an agent-based architecture - CARREL - is proposed for managing the data to be processed in carrying out recipient selection, organ and tissue allocation, ensuring adherence to legislation, and following approved protocols and preparing delivery plans.

In [14] we proposed a novel selection process of human organs for transplantation. We claimed this new process to have the potential to increase the

human organ pool for transplantation, i.e. to reduce the organ shortage for transplantation. Our thesis relays on the fact that, despite the scarcity of organs, a great number of organs available for transplantation are discarded as being deemed non-viable for that purpose. We described this proposed process in the CARREL system, and thus, we now formalize this extension.

In this report we describe the extension of CARREL's architecture in order to capture the new discarding process. Hence, in the next section we present the CARREL agent-based organization as it currently is. In section 3 we introduce the proposed human organ selection process and in section 4 we describe the formalization of the extended CARREL's architecture. In section 5 we give our conclusions.

2 The Carrel Institution

Since 1980 the number of transplant requests has been constantly increasing. As a consequence, the human transplant coordinators are currently facing significant problems in dealing with the volume of work involved in the management of requests, assignation and distribution of tissues and organs. With CARREL we intend to automate many of the task carried now a days by humans.

Two aspects can be highlighted that make transplantation management a very complex issue: (i) the need to maximize the number of successful transplants due to the scarcity of donors (ii) the complexity of the donor/recipient matching due to the diversity and multiplicity of genetic factors involved in the response to the transplant. The CARREL System is intended to automate many of the tasks that now a days are carried out by human beings. CARREL's design takes the Spanish and Catalan transplant organizations as references, both known to be examples of best practice. Hence, they constitute viable physical institutions on which to base electronic ones. The Spanish organizational model has two levels of action:

Intra-hospital: Where the role of hospital Transplant Coordinator was created to improve the coordination of all the people working at any step of the donor procurement, allocation and transplantation process.

Inter-hospital: Where an intermediary organization, the Organització CATalana de Trasplantaments [11](OCATT) for Catalonia, Organización Nacional de Transplantes [12] (ONT) for the whole of Spain was created to improve the communication and coordination of all the participating health-care transplant organizations, namely hospitals and tissue banks.

Fig. 1 depicts the inter-hospital level managed by CARREL in which we can identify the entities that interact with the CARREL system. Each TB denotes a tissue bank, each UCTx denotes a transplant coordination unit, the agency that represents a hospital member of CARREL. The ONT and OCATT denote the organ transplantation organizations that own the agent platform and act as observers.

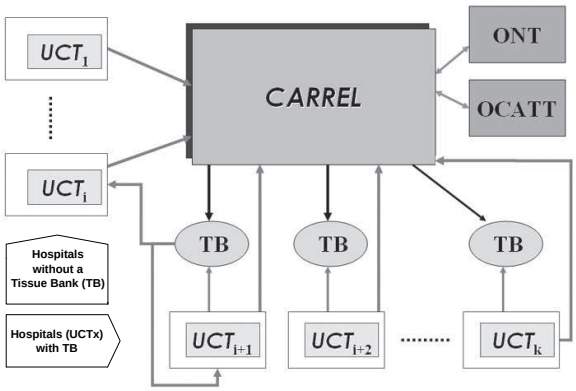

Figure 1: CARREL's environment.

We make it a requirement in our model that all hospitals, even the ones that own a tissue bank, will make their requests through CARREL in order to ensure an acceptable distribution of tissues and to ease the tracking of all tissues from extraction to implant, in the same manner as ONT and OCATT require for organs.

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

T1 to make sure that all the agents which enter into the institution behave properly (that is, that they follow the behavioral norms).

T2 to be up to date about all the available pieces in the Tissue Banks, and all the recipients that are registered in the waiting lists.

T3 to check that all hospitals and tissue banks fulfill all the requirements needed to interact with CARREL.

T4 to take care of the fulfillment of the commitments undertaken inside the CARREL system.

T5 to coordinate the piece delivery from one facility to another.

T6 to register all incidents relating to a particular piece.

A hospital becomes a member of the CARREL institution in order to make use of the services provided. In doing so, they accept to respect the norms that rule the interaction inside CARREL. Some of these norms are:

N1 All organ offers and tissue requests should be done through the CARREL institution.

N2 Hospitals must accept the outcomes of the negotiation (assignation) process.

N3 Hospitals receiving an organ or tissue from CARREL must update the institution with any relevant event related to these organs and tissues.

Each hospital member of CARREL is represented by the Transplant Coordination Unit (UCTx) that manages the intra-hospital level. Each UCTx aim is to successfully culminate any organ and tissue procurement, extraction and implantation process. Each UCTx is modelled as an agency, the roles the different agents play in this agency are presented in [4]. In this report we only identify agents in UCTx that can enter to the CARREL institution (section 4).

Before addressing the CARREL formalization (section 4) we introduce the human organ discarding process, motivating the extension to the current agent-based organization's architecture.

3 Introducing the human organ discarding process

When a potential donor is detected, a *Transplant Coordinator* has to determine which of the donor's transplantable organs are viable for that purpose. While the organs deemed as viable are offered for transplantation, the organs deemed as non-viable are not, thus, preventing all the *Transplant Units* from considering this organ transplantation to any of the potential recipients under their responsibility.

Currently in Catalonia, a world leader in transplantation, between 15 and 20 percent of the livers, 20% of the kidneys, 60% of the hearts, 85% of the lungs and 95% of the pancreas, from donors that were detected, are discarded [OCATT]. Given the scarcity of human organs for transplantation we believe no further motivation is needed for proposing an alternative human organ discarding process.

The proposed discarding process aims to reduce the discarding organs by enabling *Transplant Units* take part in the decision to whether an organ is viable or not for their patient prior to the organ offer. Two aspects underpins the proposed process: i)organs are rarely non-viable or ideal *per se*. The term ideal organ should imply an integral concept that involves donor and recipient characteristics and all the procedure performances between both [8]. ii) Different qualified professionals have different opinion on the viability for transplantation of a human organ for transplantation. Namely different physicians follow different human organ acceptability criteria.

In the following subsection we describe the current discarding process to then describe the alternative process

3.1 The Current Human Organ Discarding Process

From the moment a potential donor is detected until the moment his organs are transplanted there is a filtering process in which the different stakeholders may decline to transplant or to offer for transplantation each of the donors organs considered transplantable, viz. heart, lungs, liver, pancreas and kidneys (in fact, we only consider solid organs).

The process begins when a Transplant Coordinator (TC) detects a potential donor, in which case, after properly analyzing his characteristics, she informs the OCATT, assuming the TC is located in Catalonia, about the organs she considers viable for transplantation. If the TC is aware of any potential recipient that could match one of the donors organs, she may consult or even delegate that decision to the professionals in the Transplant Unit (TU) who are responsible of that potential recipient. This should be done before informing the OCATT and it normally happens when the recipient and the donor are located in the same hospital. If the TC considers the organ as viable but no match for the given organ is found among the potential recipients in the waiting lists of Catalonia, the OCATT will offer the organ to the ONT. Otherwise, if a recipient is found, the allocation process takes place and the organ is offered to a Catalan TU that may or may not accept the organ[1]. If refused, the organ will be offered to a different TU until final acceptance or refusal. The TU that accepts the organ has the right to discard it after or during the extraction operation, in which case it is very unlikely to have the organ transplanted. If no TU accepts the organ, it is offered to the ONT. When an organ is offered to the ONT, a similar process takes place, this time however embracing Spain and not only Catalonia. In case the organ could not be allocated, the OCATT will offer the organ to transplant organizations in Europe. If these organizations fail to allocate the organ, the OCATT will then offer it in Asia. However, this last step hardly ever occurs. If every organization fails to allocate the organ, the organ will not be retrieved from the donor.

3.2 The Alternative Human Organ Discarding Process

In order to reduce the number of human organ discards we propose an alternative discarding process in which the organs initially deemed as non-viable by a TC can also have the opportunity to end up being transplanted. This is done by enabling the Transplant Units to take active part in the human organ decision making over the viability of an organ. Namely, in this proposed discarding process, the Transplant Coordinator will offer not only the organs deemed as viable but also the organs deemed as non-viable. In this occasion the organ offers made by a TC must be followed by the arguments claiming the viability or non-viability of the offered organ. These arguments can then be counter-argued by a TU that disagrees with the TC assessment. In particular, an organ deemed as non-viable by a TC can be claimed to be viable by a TU that if providing valid reasons for transplanting the organ, this organ should not be discarded before it is offered to this TU. Given that each TU can argue over the viability or non-viability of the human organ, after the argument evaluation, to each TU the organ is labelled as either viable or non-viable. Figure 2 depicts both the flow of the current discarding process and the proposed one.

[1]It is worth mentioning that at this stage the offered organ has not yet been extracted. It is after accepting it that a Transplant Unit may extract the organ from the donor and make a more complete evaluation

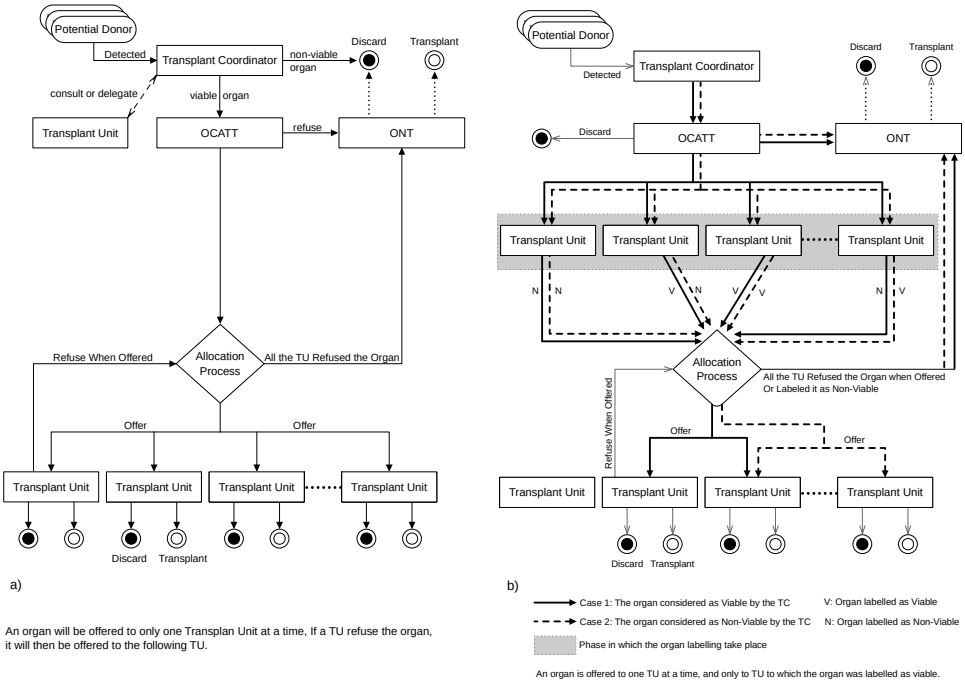

Figure 2: Flow of the Current Human Organ Discarding Process a) and the Flow of the Proposed Organ Discarding Process b). As we can see, in b) organs initially deemed as non-viable by the Transplant Coordinator (dashed lines) can end up being offered to a Transplant Unit and subsequently being transplanted. Note that, in both a) and b) an organ is not offered in parallel to the TUs but sequentially. It is only after a TU refuses the organ that it is offered to the following TU.

In [14] and [10] a more detailed description of the proposed process is given, also we describe the agents's argumentation process. In these works when framing the scenario within CARREL, for readability reasons we named *Transplant Coordinator Agent* (TCA_i) the agent that carries the TC arguments (also named Donor Agent in [10]), and *Transplant Unit Agent* (TUA_j) the agent that carries the TU arguments (also named Recipient Agent in [10]). The agent that evaluated these arguments was named *Mediator Agent* and the agent playing the role of the Transplant Organizations was named *Organization Agent* (see figure 3). In the actual extension of CARREL the tasks carried by these agents are carried out by diverse agents that in some cases carry out other tasks than the ones described in [3], [14] and [10]. These agents and in general the CARREL's extended architecture are described in the following section.

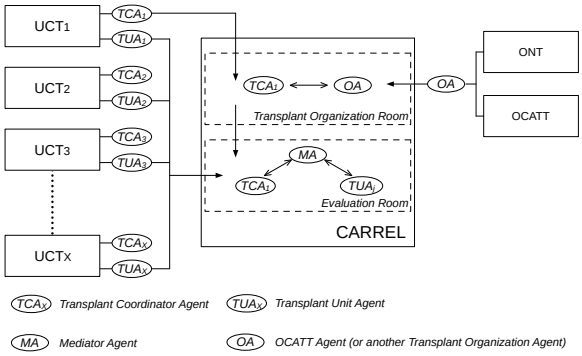

Figure 3: The CARREL System managing the human organ discarding process

4 Formalizing CARREL's extended architecture

CARREL is formalized as an electronic institution in which the interactions among a group of agents are governed by a set of norms expressed in the ISLANDER specification language [5]; CARREL can be regarded as a type of dialogical system where all the interactions are compositions of message exchanges, or illocutions, structured through agent group meetings called scenes or rooms. Each agent can be associated with one or more roles, and these roles define the rooms the agent can enter and the protocols it should follow.

Figure 4 depicts CARREL's performative structure, in which nodes denote the scenes which are connected by arcs that denote the different paths the agent can take. The arcs are labelled with the agent' roles that can follow a give path. Arcs are also labelled with either a *new* or *1*, the former indicates that the agent that enters the scene via that arc creates the scene, whereas the later denote that the agents entering via that arc are constraint to enter to a single instance of that scene.

On the upper right corner of figure 4 we can identify an elliptical node that stands for a CARREL platform. Although it does not complies with the ISLANDER's notation we use it for readability purposes to denote that agents can be headed to a different CARREL platform (we address this in section 4.2.3).

In figure 4 we can identify several scenes or meeting rooms in a broad view, each scene can be defined as follows:

Reception Room: is the scene where all the external agents should identify themselves in order to be assigned the roles they are authorized to play. If these agents are carrying either a request for a tissue or an offer of an organ, 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

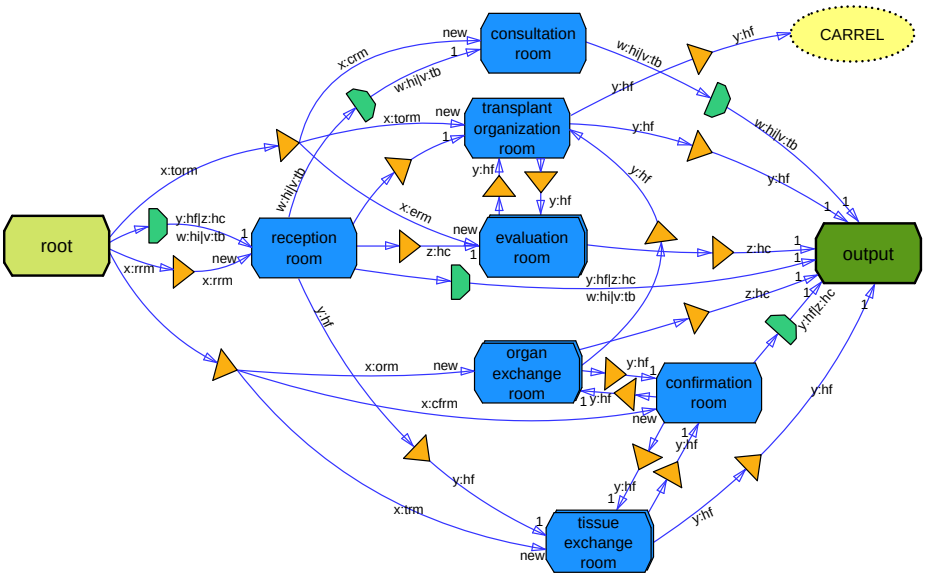

Figure 4: CARREL's performative structure.

should update the institution about tissue availability, while agents coming from hospitals should update the institution about the waiting lists and also inform it about the reception of all pieces (organs or tissues) they have received, the transplant operation and the condition of recipients. In this extension, the hospital agents also provides the reasons for any failure in the transplant process.

Transplant Organization Room: is the scene where the organ offers are directed to the suitable recipients, first within a CARREL platform and if no suitable recipient is found for that organ, the organ is offered in other CARREL platform. If no suitable recipient is found in any CARREL platform, the organ is discarded.

Evaluation Room: is the scene where the agent's arguments for the viability or non-viability of a given organ are evaluated.

Exchange Room: is the scene where assignation of pieces takes place. In fact, there are specific exchange rooms for tissue requests (*Tissue Exchange Room*) and for organ offers (*Organ Exchange Room*).

Confirmation Room: is the scene where the provisional assignments made at the exchange rooms are confirmed, whereafter a delivery plan is constructed, or cancelled, because a new request of higher priority has arrived.

The agents that can be identified in figure 4 are of two types, internal agents and external agents. The former are CARREL agents that manage each of the

scenes depicted in the figure. Whereas the later are agents that belong to either UCTx or they represent a tissue bank. In more detail, the external agents are:

***Hospital Finder Agent* (hf):** agents sent by the hospitals with a request for a potential recipient for a given organ[2] or a tissue request. If the agent is searching for a tissue, it carries the potential recipients' characteristics as well as the preferences on the characteristics of the requested tissue. CARREL must then find the most appropriate tissue among the Tissue Banks. Whereas agents offering an organ carry the donor's and organ's characteristics as well a set of arguments, these arguments represent the Transplant Coordinator's belief over the viability of the offered organ. CARREL must then find the most appropriate recipient among the waiting lists.

***Hospital Contact Agent* (hc):** agents from certain hospitals that are contacted by the institution when an organ is offered that matches the characteristics of recipients on these hospitals' waiting lists. The agents then enter to the institution in order to take part in the allocation process of the offered organ. `hc`, in this extension, can argue over the viability of the organs they are offered.

***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. If a failure in the transplant process occurs they must provide CARREL with the reasons of that failure. They can also perform queries on the CARREL's database and knowledge base.

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

And the internal agents:

***Reception Room Manager* (rrm):** manager of the *Reception Room* scene. Thus, a rrm agent is an internal agent responsible of the external agents access to CARREL.

***Tissue Exchange Room Manager* (trm):** manager of a *Tissue Exchange Room* scene. `trm`s manage the provisional tissue assignations to external agents, in particular to `hf` agents.

***Organ Exchange Room Manager* (orm):** manager of a *Organ Exchange Room* scene. `orm`s manages the provisional organ assignations to external agents, in particular to `hc` agents.

***Confirmation Room Manager* (cfrm):** manager of the *Confirmation Room* scene. The provisional assignations made by a `trm` or `orm` agent are made effective by a `cfrm` agent

[2]When a *Hospital Finder Agent* offers a human organ for transplantation, it can be regarded as searching for an appropriate recipient for the given organ, i.e. it enters to CARREL with a request potential recipient.

***Consultation Room Manager* (crm):** manager of the *Consultation Room* scene. That is, agents playing the `crm` role receive the updated information given by the hospitals and tissue banks. They also answer to the external agents' queries.

***Organization Room Manager* (orm):** manager of the *Organization Room* scene. This agent's role are introduced in the CARREL extended version in order to distribute the organs offered by the hospitals.

***Evaluation Room Manager* (erm):** manager of the *Evaluation Room* scene. `erm` agents will be in charge of managing the agents evaluation when deliberating upon the viability of a human organ.

***Institution Manager* (im):** This role (not depicted in fig. 4) is played by a single agent that registers all the events that happen inside CARREL [3] and eventually coordinates all the scene managers when the system is entering in a unsafe state[4]. This role defines what Fox and Das define as a *Guardian Agent* [6]: an agent that watches the state of the system, and only acts to avoid the system entering in dangerous or unsafe states (for instance, when the system is going to break a rule defined in the Spanish regulations about transplant allocation).

Agents enter a CARREL platform via the *root scene*. The external agents are headed to the appropriate scene, or meeting room, according to their role and their task to carry out. The room managers, on the other hand, enter to create the scene they manage. For example the *reception room manager* `rrm` creates the *reception room*. In the following subsection we define each of the performative structure scenes:

4.1 Formalizing the meeting rooms

In this subsection we define the interactions between the agents within each of the scenes of the performative structure. The agents interaction within a scene is defined by means of a *scene protocol*, that defines the accepted sequences of messages that two or more agents can utter within a scene. The protocol is represented as a directed graph, in which each node is a step or state of the conversation, and where the arcs are utterances. For each illocution there is an illocution scheme, which defines the nature of the utterance, the roles of the sender and the receiver(s) of the utterance and the information that is exchanged. In a conversation graph, some nodes are labelled with *+agent_role* and or *-agent_role*. The former indicates that this is an entry node for agents with role *agent_role* whereas the later indicates the exit nodes for agents with role *agent_role*.

[3] Spanish law on personal data security demands that all the steps of the organ allocation process to be properly registered in logs containing all important events, in order to allow further inspection.

[4] This role does not define a *centralized controller*

4.1.1 Reception Room

Agents enter to a CARREL platform via the *Reception Room* where they are registered into the platform. Registration is made after an authentication mechanism based on electronic certificates that ensures that external agents come from authorized organizations only, the authorized organization previously received the electronic certificate. Once the sender has been identified as authorized, the external agents are then directed to a appropriate room according to their roles and task to carry out.

Figure 5 depicts the scene protocol that starts with an agent request for admission (message 1a,1b,1c,1d), if the agent request is not accepted the RRM directs the agent to an exit node $W2$ (message 2a, 2b, 2c or 2d). Otherwise it is accepted (messages 3a, 3b, 3c, 3d). According to the role of the incoming agent:

- Both the hospital information agent (`hi`) and the tissue bank agent (`tb`) are headed to the *Consultation Room*,exit state w_2 (message 3a and 3b).
- A hospital contact agents (`hc`) enters CARREL to take part in the allocation process of an offered organ, it enters as a response to a call made by the institution. Thus, after receiving message 3c, `hc` has to provide `rrm` with the identification of the institution's call as well as with the recipient's information and the arguments claiming the viability or non-viability of the offered organ (messages 8). If `rrm` accepts the content of message 8, it directs `hc` to the appropriate *Evaluation Room* $W13$ (message 9(OK)) otherwise the agent is not accepted $W10$ (message 9(faulty-void)).
- Agents with a request for either a tissue or a recipient for an organ are directed to state $W4$ (message 3d) from which, after providing the pertinent information (message 4a or 4b), are directed to a *Tissue Exchange Room* when requesting a tissue or to a *Transplant Organization Room* when offering an organ (message 7a and 7b resp.), as soon as the appropriate rooms are available (message 6a or 6b). If their petition is denied they are directed to the exit node $W10$ (message 5(faulty-void)). Note that in this extended architecture, `hf` offering an organ must also provide the arguments to *why* they deem the offered organ to be viable or not.

4.1.2 Consultation Room

The *Consultation Room* allows agents coming from hospitals or tissue banks to keep CARREL updated with the information needed to manage the assignation of organs and tissues. Figure 7 captures the protocol of the *Consultation Room*. Agent `hi` can inform of the arrival of a piece to the hospital (message 10), of the evaluation of a transplanted pieces (message 11, which may include the arguments to *why* a failure on the transplant process occurred), it can also provide CARREL with up-to-date information of the recipient waiting list for a type of organ (message 13) as well of the urgency of these patients (message

Msg♯	Illocution
1a	(request (?y hf) (?x rrm) (admission ?id_agent ?role ?hospital_certificate))
1b	(request (?z hc) (?x rrm) (admission ?id_agent ?role ?hospital_certificate))
1c	(request (?w *hi*) (?x rrm) (admission ?id_agent ?role ?hospital_certificate))
1d	(request (?v tb) (?x rrm) (admission ?id_agent ?role ?tissue_banck_certificate))
2a	(deny (!x rrm) (!y hf) (deny ?deny_reason))
2b	(deny (!x rrm) (!z hc) (deny ?deny_reason))
2c	(deny (!x rrm) (!w hi) (deny ?deny_reason))
2d	(deny (!x rrm) (!v tb) (deny ?deny_reason))
3a	(accept (!x rrm) (!v tb) (accept_hc))
3b	(accept (!x rrm) (!w hi) (accept_tb))
3c	(accept (!x rrm) (!y hc) (accept_hi))
3d	(accept (!x rrm) (!x hf) (accept_hf))
4a	(inform (!y hf) (!x rrm) (petition_tissue ?id_hospital ?urgency_level ?time_to_deliver ?piece_type (?piece_parameters) (?info_recipient)))
4b	(inform (!y hf) (!x rrm) (petition_organ ?id_hospital ?time_for_availability ?piece_type (?piece_parameters) (?info_donor) (?arguments_is_viable))
5	(inform (!x rrm) (!y hf) (petition_state ?id_petition ?ok))
6a	(inform (!x rrm) (!y hf) (init_exchange ?id_tissue_exchange_room))
6b	(inform (!x rrm) (!y hf) (init_exchange ?id_organization_room))
7a	(request (!y hf) (!x rrm) (tissue_exchange_entrance_request !id_tissue_exchange_room))
7b	(request (!y hf) (!x rrm) (organization_entrance_request !id_organization_room))
8	(inform (!z hc) (!x rrm) (called_for_organ ?id_hospital !id_petition (?info_recipient) (?arguments_is_viable))
9	(inform (!x rrm) (!z hc) (called_state !id_petition ?ok))

Figure 5: The illocutions for the Reception room

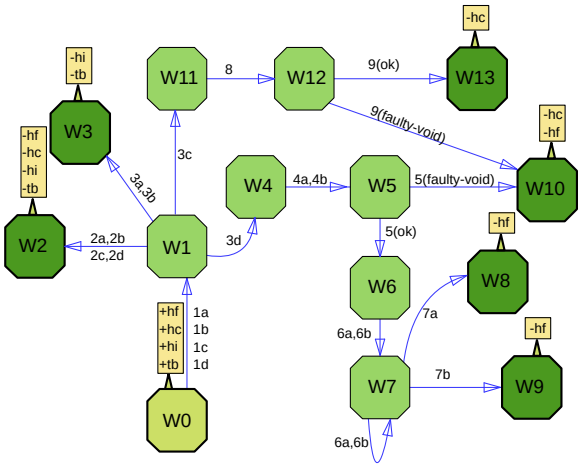

Figure 6: Conversation graph for the Reception room

14). Agent `tb` updates CARREL with the available tissues for transplantation via message 12.

Both `hi` and `tb` can also perform queries (message 16 and 17) about historical facts (e.g., statistics on successful cornea transplantations over a certain period). The queries are answered (message 18) 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 Control* model [7]. When the incoming agents have performed all the queries and notifications, they exit the CARREL system (message 19a and 19b).

4.1.3 Transplant Organization Room

In order to distribute the organ offers to the appropriate recipients, CARREL uses the *Transplant Organization Room*, where of the task carried out by the transplant organizations (such as OCATT or ONT) take place. The scene protocol is presented in figure 9 and 10. The agent searching for an appropriate recipient makes a petition to offer an organ to the `tomr` agent (message 20). If there are potential recipients in this CARREL's platform waiting list for whom the offered organ is suitable `hf` will be directed to the *Evaluation Room* (message 23), where his argument and the potential recipient's arguments are evaluated. If no potential recipients are found in this platform `hf` is directed to another CARREL's platform (message 21). CARREL has the right to not offer an organ given by a `hf` (message 22). In figure 4 capturing CARREL's performative structure, we identify an arc connecting the *Transplant Organization Room* with another CARREL platform. As mentioned above, this does not complies with the ISLANDER notation. This captures the result of the institution's message 21, in which `hf` is headed to the *root* node of another CARREL platform, but

Msg♯	Illocution
10	(inform (?w hi) (?x crm) (piece_arrival ?id_hospital ?id_tissue_bank ?id_piece (?state)))
11	(inform (?w hi) (?x crm) (transplantation_eval ?id_piece ?id_recipient ?date (?info_transplantation)))
12	(inform (?v tb) (?x crm) (tissue_bank_update ?id_tissue_bank ?id_piece (?specifications)))
13	(inform (?w hi) (?x crm) (waiting_list_update ?id_hospital ?piece_type ?id_recipient ?time_in (?info_recipient)))
14	(inform (?w hi) (?x crm) (maximum_urgency_level_update ?id_hospital ?piece_type ?id_recipient ?urgency_level ?time_in (?info_recipient)))
15a	(inform (!x crm) (!v tb) (notification_ack !id_piece ?ok))
15b	(inform (!x crm) (!w hi) (notification_ack !id_piece ?ok))
15c	(inform (!x crm) (!w hi) (notification_ack !id_recipient ?ok))
16	(query-if (?w hi) (?x crm) (?query))
17	(query-ref (?w hi) (?x crm) (?query))
18	(inform (!x crm) (!w hi) (query_results (?results))
19a	(request (?v tb) (u im) (end))
19b	(request (?w hi) (u im) (end))

Figure 7: Illocutions for the Consultation room

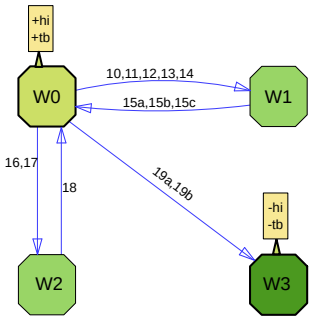

Figure 8: Conversation graph for the Consultation room

Msg♯	Illocution
20	(request (?y hf) (?x torm) (organ_offer ?id_petition)
21	(inform (!x torm) (!y hf) (delegate_organ_offer !id_petition ?reason)))
22	(inform (!x torm) (!y hf) (discard_organ_offer !id_petition ?reason)))
23	(inform (!x torm) (!y hf) (accept_organ_offer !id_petition)))

Figure 9: The illocutions for the Transplant Organization Room

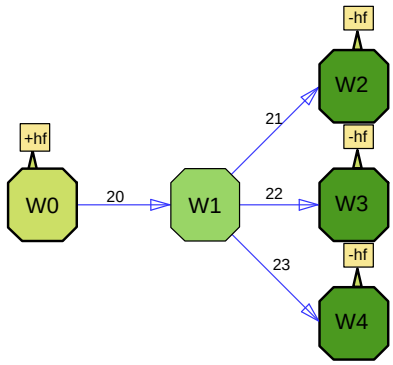

Figure 10: Conversation graph for the Transplant Organization Room

in order to do so, `hf` has to exit the current CARREL platform via the *output* node. Namely, we introduced the arc connecting the *Transplant Organization Room* with another CARREL platform for readability purposes.

4.1.4 Evaluation Room

The arguments given by the agents when deliberating over the viability of an organ are evaluated in the *Evaluation Room*. This new scene enables the recovery of organs initially deemed as non-viable. The protocol of this scene is captured in figure 11. This scene begins with an agent offering an organ entering the scene with the assigned organ offer identification given in the `Transplant Organization Room` in node $W0$. Subsequently, the agents representing the potential recipients `hc` enter to the scene in node $W1$ as an answer to the institution's call (message 24). Each `hc` provides the information of the potential recipient as well as the arguments that support their belief to whether the offered organ is viable for their recipient (message 25). The `erm` evaluates the given arguments and informs each `hc` whether the organ was deemed viable or not for their patient (messages 26a and 26b) if the arguments given by the `hc` are not accepted a reason for their rejection is also given. Once all the `hc` answered to

Msg♯	Illocution
24	(request (!x erm) (hc) (call_for_recipient !id_petition ?time_for_availability ?piece_type (?piece_parameters) (?info_donor) (?arguments_is_viable)))
25	(inform (?z hc) (!x erm) (call_answer !id_petition ?id_recipient ?id_hospital (?info_recipient) (?arguments_is_viable)))
26a	(inform (!x erm) (!z hc) (organ_viability !id_recipient non-viable (?reason)))
26b	(inform (!x erm) (!z hc) (organ_viability !id_recipient viable (?reason)))
27	(request (!x erm) (all) (allin))
28	!evaluation_timeout
29	(request (!x erm) (all) (recipient_not_found reason !id_petition))
30	(request (?x erm) (all) (recipient_found !id_petition (?viable_hc)))

Figure 11: The illocutions for the Evaluation Room

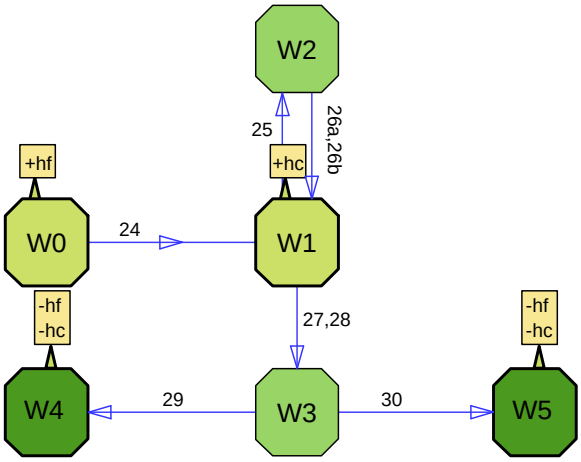

Figure 12: Conversation graph for the Evaluation room

Msg♯	Illocution
31	(query-if (?x orm) (?z hc) (organ_offer_accept ?id_petition))
32	(inform (!z hc) (!x orm) (organ_offer !id_petition refuse ?reason))
33	(inform (!z hc) (!x orm) (organ_offer !id_petition accept))
34	(inform (!x orm) (all) (recipient_found !id_petition !id_recipient !id_hospital))
35	(inform (!x orm) (all) (recipient_not_found reason ?id_petition)))

Figure 13: The illocutions for the Organ Exchange Room

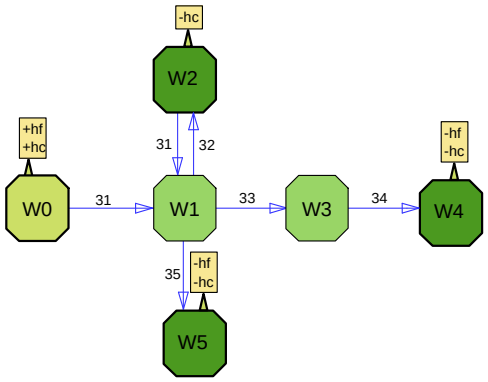

Figure 14: Conversation graph for the Organ Exchange room

the institution's call (message 27) or when the evaluation time is out (message 28), if no recipient was found for the offered organ, `hf` is headed again to the *Transplant Organization Room* (message 29). Otherwise, the `hf` and all the `hc` to whom the organ was labelled as viable are directed to the *Organ Exchange Room* (message 30).

4.1.5 Organ Exchange Room

After the agents' arguments are evaluated in the *Evaluation Room* a prioritized queue with the `hc` that have labelled the organ as viable is available for the agents playing the *Organ Exchange Room Manager* role `orm`. On the basis of this prioritized queue `orm` will attempt to arrive to a provisional organ assignation to a `hc` agent. Thus, following the queue order, `orm` queries each `hc` whether they accept or reject the offered organ (see fig. 13 for the scene protocol). This is done as long as the `hc` agents refuse the organ (message 32). Once a `hc` accepts the offered organ (message 33) this agent and the `hf` are headed to

the *Confirmation Room* (message 34). If no potential recipient is found for the offered organ, `hf` is directed to the *Transplant Organization Room* (message 35).

4.1.6 Tissue Exchange Room

The *Tissue Exchange Room* is the place where negotiation over tissues is performed. The protocol of this scene is shown in figure 15: `hf` asks the scene manager for tissue offers (tissues matching the requirements included in their petition) (message 36). Then the scene manager provides a list of available tissues (message 37) that is evaluated by the external agent `hf` (message 38). With this information the scene manager can make a provisional assignment and solve collisions (two agents interested in the same piece). When this provisional assignment is delivered (message 39) `hf` exits the scene to go to the *Confirmation Room* represented by state $W4$. There is an alternative path for the case when there are no available pieces matching the requirements described in the petition (message 37 with null list). In this case `hf` requests an exit permission from the institution (message 40, exit state $W6$), 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].

4.1.7 Confirmation Room

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 17 shows the protocol of this scene: the agent can analyze the assigned piece data and then accept or refuse it (messages 42a or 42b). If an agent (either `hc` or `hf`) 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 (messages 43a or 43b), and then it exits the CARREL system (exit state $W4$). When there is a request with higher priority that needs the piece provisionally assigned to an agent a conflict arises. To solve the conflict the scene manager notifies the agent that the assignment has been withdrawn (message 44a or 44b) and that he is then entitled to a fresh request for another piece in the case of the `hf` requesting a tissue, if available, (message 45) to be negotiated again in the *Exchange Room* whence it came. `hc` exits the institution if the organ assignation could not be completed.

4.2 CARREL overview

The presented extension to the CARREL architecture enables to support the new requirements raised with the proposal of incorporating into CARREL the discarding process presented in [14]. Thus, the arguments representing the beliefs of a *Transplant Coordinator* and a *Transplant Unit* about the viability of the offered organ can now be managed within the CARREL System, given that these arguments can know be carried by `hf` and `hc`, respectively and evaluated

Msg♯	Illocution
36	(query-if (?y hf) (?x term) (offer_list ?id_petition))
37	(inform (!x term) (!y hf) (offer_list !id_petition (list (?id_piece1 ?info_piece1) ...(?id_piecen ?info_piecen)))
38	(inform (!y hf) (!x term) (weighted_list !id_petition (list (!id_piece1 ?weight) ... (!id_piece1 ?weight)))
39	(query-if (!x term) (!y hf) (piece_offer (?id_petition ?id_piece ?cost_estimation)))
40	(request (!x hf) (u im) (exit ?exit_reason))

Figure 15: The illocutions for the Tissue Exchange Room

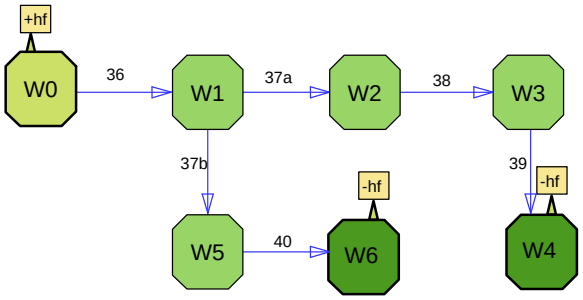

Figure 16: Conversation graph for the Tissue Exchange room

Msg♯	Illocution
41a	(request (!y hf) (u im) (exit ?exit_reason)
41b	(request (!z hc) (u im) (exit ?exit_reason)
42a	(inform (?y hf) (?x cfrm) (piece_eval ?id_petition ?id_piece ?accepted))
42b	(inform (?z hc) (?x cfrm) (piece_eval ?id_petition ?id_piece ?accepted))
43a	(inform (!x cfrm) (!y hf) (piece_delivery ?id_petition ?id_hospital ?id_tissue_bank ?delivery_plan))
43b	(inform (!x cfrm) (!z hc) (piece_delivery ?id_petition ?id_hospital_donor ?id_hospital_recipient ?delivery_plan))
44a	(inform (!x cfrm) (!y hf) (piece_reassigned_exception ?id_petition ?id_piece ?reassignment_reason))
44b	(inform (!x cfrm) (!z hc) (piece_reassigned_exception ?id_petition ?id_piece ?reassignment_reason))
45	(query-if (?y hf) (?x cfrm) (another_offer_list ?id_petition))

Figure 17: Illocutions for the Confirmation room

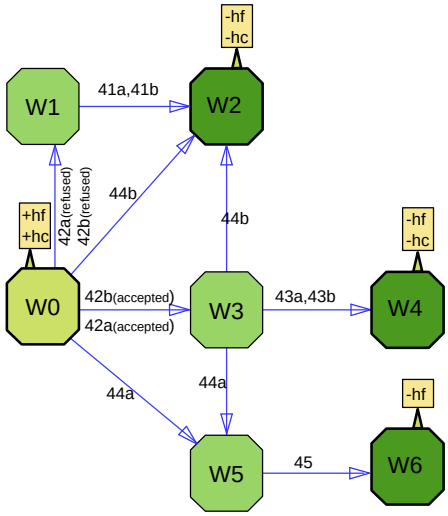

Figure 18: Conversation graph for the Confirmation room

```
(define-performative-structure
 carr-performative-structure as
 scenes=
  ((root root-scene)                                        ; declare the
   (r-room reception-room-scene)                            ; scenes comprising
   (te-room tissue-exchange-room-scene list                 ; the institution
   (e-room evaluation--room-scene list)
   (to-room transplant-organization-room-scene)
   (oe-room organ-exchange-room-scene list)
   (cf-room confirmation-room-scene)
   (cs-room consultation-room-scene)
   (output output-scene)
  )
 transitions =                                              ; set up the transitions
  ((createR-room AND)
   (toR-room OR)
       ...

 connections =                                               ; and set up the connections
  ((root toR-room (((x hf)))(((y hc)))(((z hi)))(((w tb))))
   ...
initial-scene = root
final-scene = output
)

(define-dialogic-framework carr-dialogic-framework as
 ontology = carr-ontology
 representation-language = first-order-logic
 illocutionary-particles = (......)
 external-roles = (hf, hc, hi, tb)                          ; list all the roles
 internal-roles = (im, rrm, trm, orm, cfrm, crm, torm, erm)  ; that participating
 role-hierarchy = ((im rrm) (im trm) (im orm)                ; agents may play and
                  (im cfrm) (im crm) (im torm) (im erm)      ; how the roles are related
                  )                                          ; to one another
 social-structure = ((im > rrm) (im > trm)...(rrm > tb))
)

(define-scene e-room as                                      ;
 roles =  (erm hf hc)                                        ; contained in a particular scene
 scene-dialogic-framework =  e-room-df                       ; specifying which roles may participate
 state = (W0 W1 W2 W3 W4 W5)                                 ; the rest is just a textual
 initial-state = W0                                          ; representation of a finite state
 final-states =  (W4 W5)                                     ; machine
 access-state = ((erm (W0)) (hf (W0)) (hc (W1)))
 exit-states = ((trm (W4 W5)) (hf (W4 W5)) (hf (W4 W5)))
 agents-per-role = ((1 <= trm  <= 1) (1 <= hf  <= 1) (0 <= hc))
 conections =                                               ; transition labels are speech acts
  ((W0 W1 (request (?x erm) (hc) (call_for_recipient ?id_petition ?time_for_availability ?piece_type
(?piece_parameters) (?info_donor)(?arguments_is_viable)))))
   (W1 W2 (inform  (?z hc) (!x erm) (call_answer offer_list ?id_recipient
   !id_petition ?id_hospital (?info_recipient) (?arguments_is_viable))))
   ...
   (W3 W5 (request (!x erm) (all) (recipient_found !id_petition) ))
  )
)
```

Figure 19: A code fragment of the CARREL System's specification

in the *Evaluation Room*. Note that the `hi` can also provide arguments, these arguments represent the *Transplant Unit*'s justification to any failure in the transplant process and are carried by the `hi` into the *Consultation Room*. In figure 20 we can identify the agents that conform the CARREL agent-based organization. The different arrow types in the figure denote different interactions. The ACKB, that stands for Acceptability Criteria Knowledge Base, can be regarded as the knowledge base that capture the valid criteria on which a decision to whether an organ is viable or not can be taken.The CBRe, that stands for Case-Based Reasoning Engine, evaluates the validity of the arguments used by the agents. Both ACKB and CBRe are described in [14]. We are currently designing both ACKB and CBRe from which the *Criteria Agent* (see fig. 20) can derive the validity of the given criteria for accepting or rejecting a human organ used by the external agents. The agents with a scene managing role interact with the external agents, whereas agents playing the roles of *Planner Agent*, *Data Base Agent* or *Criteria Agent* support the former providing them with the required information, such as delivery plans, or a potential recipient's waiting lists. These agents are also responsible of updating the bases (Data Base, Case-Based and the Acceptability Criteria Knowledge Base) when required.

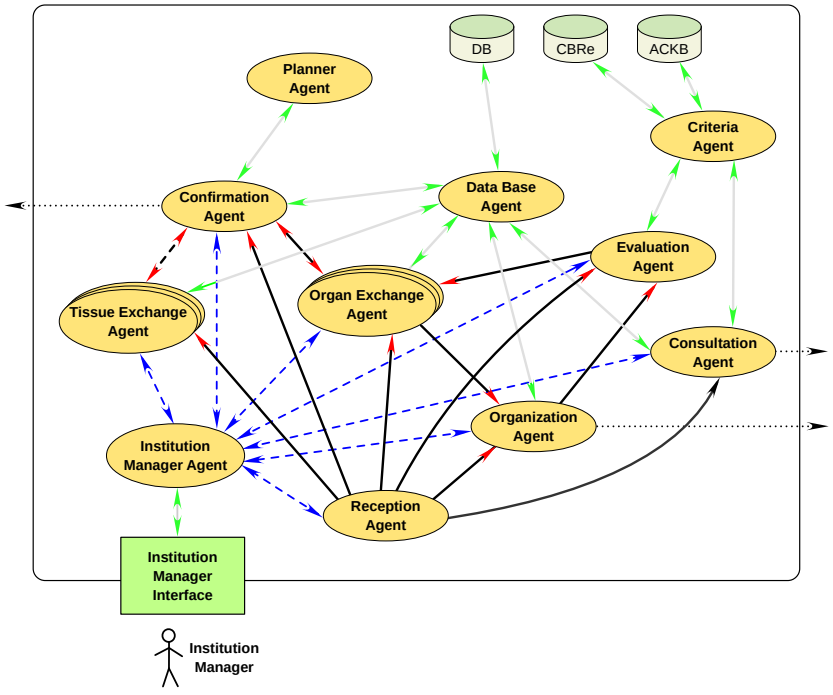

Figure 20: The Carrel agent based Organization

5 Conclusions

CARREL is an agent-based organization designed to improve the overall transplantation process. Previous concerns in the formalization of CARREL were related to normative aspects. Namely, *how* to capture all the legal issues related to the transplant process when certain tasks are no longer carried out by humans but are automated. The extension to CARREL architecture described in this report stem from another concern, the ability of the software agents to reason about the medical criteria. In particular, we center our efforts on the ability of the software agents to reason about the human organ acceptability criteria, given that it is a particularly ill-defined problem and at the same time it is a critical issue within the human organ transplantation domain (see [1]). Thus, the extension of CARREL's architecture described in this report will enable agents to argue over the viability of a human organ.

The integration to CARREL of our work presented in [14] is still work in progress given that components such as the ACKB and CBRe are yet to be designed. Also the formalization of the CARREL federation, already mentioned in [13], has not yet been accomplished. Hence, remaining to be addressed in forthcoming work

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