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Abstract Service negotiation is a complex activity, especially in complex domains such as healthcare. The provision of healthcare services typically involves the coordination of several professionals with different skills and locations. There is usually negotiation between healthcare service providers as different services have specific constraints, variables, and features (scheduling, waiting lists, availability of resources, etc.), which may conflict with each other. While automating the negotiation processes by using software can improve the efficiency and quality of healthcare services, most of the existing negotiation automations are positional bargaining in nature, and are not suitable for complex scenarios in healthcare services. This paper proposes a cooperative-competitive negotiation model that enables negotiating parties to share their knowledge and work toward optimal solutions. In this model, patients and healthcare providers work together to develop a patient-centered treatment plan. We further automate the new negotiation model with software agents.

Key words: Negotiation automation, interest-based negotiation, cooperative-competitive negotiation, multiagent systems, artificial intelligence, eHealth, health service integration.

1 Introduction

Our quality of life and wellbeing are directly associated with the availability of healthcare services. Healthcare is a complex domain involving professionals having a wide range of expertise, knowledge, skills, and abilities (ranging from family doctors to medical specialists, nurses, laboratory technicians, and social workers). Healthcare treatment often involves a combination of different skills, needs, and resources, which may be located in different places. There is widespread negotiation between healthcare service providers, as different partners have their own constraints, variables, and features (scheduling, waiting lists, availability of resources, etc.), which may conflict with each other. Negotiations between healthcare providers and patients are very important to achieve ideal, patient-centered medical treatment. However, such negotiations are costly and complex because of the number of entities and variables that need to be taken into consideration. It is therefore challenging to reach optimal solutions.

The automation of negotiation processes using software components can both increase the negotiation efficiency and improve the quality of healthcare services. Intelligent agents can be very useful in this context. Agents exhibit the characteristics of autonomy (operate without direct human intervention), social ability (interact with other agents), reactivity (perceive their environment and respond in a timely fashion to changes that occur), and proactiveness (exhibit goal-directed behavior by taking the initiative). Agents are able to communicate with each other and achieve specific goals by engaging in complex dialogues to negotiate, coordinate, and collaborate. If we are able to model in agents the knowledge of healthcare services possessed by human professionals, then the healthcare service negotiation process can be complemented by the multiagent system.

Over the past decade, agent-based approaches have been applied in many healthcare applications, such as medical data management, decision-support systems, planning, resource allocation, and remote care. Several multiagent systems have been proposed to support the negotiation and coordination process for medical professionals' collaborative diagnosis, treatment planning, and care management. However, these agent systems mainly support information sharing and communication between medical professionals. The agents therefore cannot adequately negotiate with each other on behalf of human beings. To achieve automated negotiation, computational negotiation models are needed.

Most of the existing negotiation models are positional bargaining types of negotiations, where participants have to compromise if conflicts occur. These types of negotiations are not suitable for healthcare service negotiation. Healthcare negotiations should be cooperative, where all negotiators pursue the mutual goal of providing quality services to patients. This paper proposes a cooperative-competitive negotiation model that enables negotiating parties to share their knowledge and develop optimal solutions. In this model, the intelligent agents of patients and healthcare service providers work together to develop a patient-centered treatment plan.

The rest of the paper is organized as follows: Section 2 introduces the negotiation strategies and negotiation automation approaches; Section 3 proposes our cooperative-competitive negotiation strategy; Section 4 introduces the computational model of cooperative-competitive negotiation agents; Section 5 illustrates the proposed method using an example; and Section 6 concludes the paper.

2 Negotiation Strategies and Automation Approaches

A simple and traditional negotiation strategy is *Position-Based Negotiation* (PBN), which focuses on bargaining positions, such as price, time, and quantity. In a PBN, the negotiating parties are firmly committed to their arguing positions. The positions indicate the desires of the negotiating parties, and reflect their perspective on a certain issue. It does not express the reason for having the position, nor does it afford others the opportunity to consider their own interests. In position-based negotiation, the involved parties argue only their positions, and the underlying reasons for their positions may never be explicitly mentioned. If there is no agreement on the arguing positions, the negotiation fails. Below is an example involving a blood test appointment booking using position-based negotiation, in which no agreement was reached.

Patient: Can I book a blood test in ABC Lab on Saturday morning?
Nurse: Sorry, ABC Lab is not open on Saturday.
Patient: Thanks, Bye.

Interest-Based Negotiation (IBN) focuses on satisfying the underlying reasons rather than meeting the stated positions. The interests of a negotiation party reflect the underlying concerns, needs, or desires behind an issue. In interest-based negotiation, the interests of participants are identified and explored, helping each party to understand the others' perspectives. By discussing the reasons behind the positions and thinking of alternatives, a mutually acceptable agreement is more likely to be reached. In the above example, suppose the interest of the patient is to find a pathology collection center that can do painless blood testing for her son (such as using EMLA Cream to numb the skin). If the nurse can propose an alternative solution to meet the patient's interest, they can reach an agreement. For example:

Patient: Can I book a blood test in ABC Lab on Saturday morning?

Nurse: Sorry, ABC Lab is not open on Saturday. Why not try XYZ Lab?
Patient: I prefer ABC Lab is because it has the angel cream (EMLA Cream) for children.
Nurse: XYZ Lab started to provide the angel cream for kids this year. Do you want me to book it for you?
Patient: Yes, please.

Negotiating certain issues is similar to multiple parties attempting to divide a pie. In position-based negotiation, the primary concern is to satisfy one's own desires; meeting the needs of the other side is unimportant, and all parties desire as big a slice of the pie as possible. However, in interest-based negotiation, one seeks an arrangement that adequately satisfies both sides. All parties view negotiation as an inventive process for integrating interests and generating new opportunities; when it is time to divide the pie, all participants want to hold the knife together to affirm mutual trust and good faith, and all want to achieve a win-win outcome. The effectiveness of any health system relies on the functioning of its many interdependent parts, as each component depends on the others' achievements. The act of negotiation with this understanding is a method of adjusting the balance to ensure both fairness and mutual gain.

Although interest-based negotiation is considered to be better than position-based negotiation, it has not been reported in eHealth services. A possible reason is that no effective computational models and negotiation automation mechanisms have been designed for healthcare services. Additionally, existing interest-based negotiations are mainly used for two parties. Each negotiator tries to find alternative solutions to avoid conflicts. However, in healthcare services, there are often multiple parties involved, whose relationships have both cooperative and competitive characteristics. The parties have to cooperate with each other to come up with medical solutions, and their goals include finding the best services for patients from among the competitive options. More comprehensive information exchanges (like knowledge exchange) are needed, rather than simple interests. Therefore, in this paper, we propose a cooperative-competitive model for healthcare service negotiation. We will further automate the new negotiation model with software agents.

The formalization of negotiation has received a great deal of attention from the agent community. An intelligent agent is an autonomous component that is used for constructing open, complex, and dynamic systems, and is one of the most suitable software entities to carry out negotiation automation. Negotiation is a core part of agent interactions. Jennings et al. defined negotiation as the process by which a group of agents tries to come to a mutually acceptable agreement on some matter.

The research into negotiation automation employing software agents can be categorized into three main approaches: game theoretic approach, heuristic approach, and argumentation-based approach. The game theoretic approach applies game theory techniques to find dominant strategies for each participant. The heuristic-based approach applies heuristic decision making during the course of negotiation. In both approaches, negotiators do not exchange additional information other than the proposal. These two approaches are mainly used for position-based negotiations. These approaches are not suitable in situations where negotiators have incomplete information about the environment, while they need to collaborate to accomplish tasks. For example, in the healthcare domain, diabetes professors, nurses, and laboratory technicians all have expertise in their own areas, but have limited knowledge in other areas, so they need to collaborate with each other to provide diabetes management services.

An argumentation-based approach allows negotiators to exchange additional information. It enables agents to gain a wider understanding of their counterparts, which makes it easier to resolve certain conflicts, especially those that are due to incomplete knowledge. Argumentation-based negotiation is a broad term, and refers to all the negotiations that exchange additional meta-level information (arguments) during the negotiation process. This agent based approach makes the interest-based negotiation strategy achievable, as negotiators can exchange their pursuing interests/goals through argumentation. Several studies use the argumentation-based approach to achieve interest-based negotiation strategies which mainly focus on the business domain; however, little progress has been reported into the use of argumentation-based negotiation for healthcare services.

3 Cooperative-Competitive Negotiation Strategy

Traditionally, people use negotiation as a means of compromise in order to reach an agreement. In general, negotiation is defined as an interactive process that aims to realize an agreement among multiple parties. All parties have their own goals, and work for their own interests, so they naturally compete with each other. In some common environments, it is desirable for the parties to cooperate in order to achieve efficient and mutually beneficial, win-win solutions. That is, cooperation and competition are both very important in the negotiation process. The provision of healthcare services is an environment that often requires cooperation from competitive parties. However, such negotiation has been little reported in eHealth. In this paper, we propose a new cooperative-competitive negotiation strategy that focuses on finding mutually beneficial solutions. This strategy provides negotiating parties with opportunities to make general plans (even if they are self-interested) and to make full use of all parties' capabilities to maximize the overall benefit.

Cooperative-Competitive Negotiation is a more comprehensive interest-based negotiation where the negotiating parties use their combined knowledge to create an optimal solution that is acceptable to all parties. During the negotiation process, negotiators can share information to have a more comprehensive view. They can exchange goals to pursue mutual benefits and they can share capabilities to develop cooperative solutions. Meanwhile, each party works towards their own benefits and tries to find optimal solutions from among competitive options. Hence, this is a new negotiating model which advances the existing interest-based negotiation approach by introducing cooperative-competitive characteristics. Using cooperative-competitive negotiation, the blood test booking example may instead be as follows:

Patient: Can I book a blood test and urine test in ABC Lab on Saturday morning?
Nurse: Sorry, ABC Lab is not open on Saturday. Why not try XYZ Lab?
Patient: I prefer ABC Lab is because it has the angel cream (EMLA Cream) for children.
Nurse: XYZ Lab started to provide the angel cream for kids this year. Do you want me to book it for you?
Patient: Yes, please. How long before I can get the results?
Nurse: You can get the result for the urine test immediately and 7 working days for the blood test.
Lab L: Our lab also uses angel cream and it only takes 3 working days for the blood test results. But we don't do urine tests.

Patient: Excellent, please book Lab L for the blood test and XYZ Lab for the urine test.

In the example, the two labs worked together to provide a better service for the patient. It demonstrated that a good negotiating strategy should exhibit the following characteristics:

- Finding alternative solutions when there is no agreement on the stated positions;
- Exchanging information to form a globalized view;
- Choosing the optimal solution from a set of competitive solutions;
- Seeking cooperative solutions that aggregate individual's capabilities; and
- Pursuing mutual benefits.

The cooperative-competitive negotiation model can be distinguished from the existing interest-based negotiation as the latter focuses on individual alternative solution seeking so as to avoid conflicts, whereas our model focuses on multiple parties' joint development of a solution to resolve conflicts; hence, it is a cooperative solution. The existing interest-based negotiations aim to find a solution without conflict. This model is able to construct the optimal solution during the process of searching for non-conflicting solutions; hence, it is a competitive solution.

4 Cooperative-Competitive Negotiation Agent Modeling

The negotiation agents that were modeled reside in a multiagent environment and work together to arrange healthcare services. Each agent represents either a medical professional (such as a family doctor, specialist or nurse) or a patient. The agents are equipped with knowledge of their principals. When an agent proposes a service plan, other agents will join in a negotiation process to collaboratively verify and improve the plan. This section introduces the computational model of the negotiation agents, and section 5 will illustrate the model using an example.

4.1 Negotiation Dialogue Types

Agents require dialogue protocols to communicate with each other. Several dialogue types are proposed in literature for human or agent communication. An influential work is the typology of primary dialogue types proposed by Walton and Krabbe. This categorization is based on the information possessed by the participants at the commencement of a dialogue, their individual goals for the dialogue, and the goals that are mutually shared. The dialogue types include Persuasion Dialogue, Negotiation, Inquiry, Deliberation, Information seeking and Eristics.

The eristic type of dialogue serves primarily as a substitute for (physical) fighting, and is therefore not suitable for healthcare service negotiation. The dialogue types proposed by Walton and Krabbe are not exhaustive; instead, they provide the primary dialogue types for other researchers to study human or agent communications. Mcburney and Parsons developed a logic-based formalism for modeling the five dialogue types in Walton and Krabbe's typology between software agents. McBurney and Parsons also defined five locutions for argumentation in agent interaction protocols: Assert, Question, Challenge, Justify, and Retract. Heras, Rebollo, and Julian proposed a dialogue game protocol for agents to argue about recommendations in social networks, which contain the following locutions: Statement, Withdrawal, Question, Critical Attack, and Challenge.

These studies revealed some necessary atomic dialogue types in agent negotiation protocols, such as dialogues to express positions, justify positions, and exchange information. Considering that our agents are to arrange healthcare services for patients, the following dialogue types will be used:

– *Proposal*: A proposal is a proposed care plan (treatment plan) involving several healthcare services;

– *Proposal Acceptance/Rejection*: The decision on whether to accept or reject a proposal depends on many factors, including whether a patient is satisfied with the services and whether the services are available;

– *Challenge*: Ask for the reasons of a proposal;

– *Justification*: Provide proof for a proposal; and

– *Information Seeking/Information Providing:* An agent usually has incomplete knowledge, and its decision is made based on limited local information. If the agents exchange information during the negotiation, they may find more options; hence, there is a greater chance that an agreement will be reached.

4.2 Knowledge Model of Negotiation Agents

Agents are autonomous entities that make decisions independently and work toward their goals. The goal of negotiation agents is to find a proper set of services. A complex service can be considered as a composition of sub services, which may be further decomposed into the next level sub services. The services and the sub services form a hierarchical structure. The relationships of the services are the knowledge which the agents use to work out the treatment plans.

Knowledge Base. The knowledge base of a negotiation agent is a collection of services and relationships among services. It is defined as a 3-tuple $KB = \langle S, R, P \rangle$, where

$$S = \{ s_i \mid i = 1, 2, \ldots n\}$$
$$R = \{ r_i\!: s_{i0} \rightarrow s_{i1}, s_{i2}, \ldots s_{ik} \mid s_{i0}, s_{i1}, \ldots s_{ik} \in S, i = 1, 2, \ldots m\}$$
$$P = \{ p_i \mid i = 1, 2, \ldots n \}$$

Here, S is a service set. R is a relationship set where each relationship r_i describes how a complex service is decomposed into sub services. s_{i0} is defined as the head of a relationship, $s_{i1}, s_{i2}, \ldots, s_{ik}$ are defined as the tail of a relationship.

P is a property set and is discussed later. p_i contains the properties relevant to s_i, such as cost, waiting time, quality of service, and facilities.

According to the super-sub service relationship, services of a negotiation agent form a hierarchy (a network), and it is not necessarily a tree.

Atom Service. A service s is called an atom service if there is no relationship such that it has s as the head and other services as the tail. Atom services are services that cannot be decomposed into other sub services. They correspond to the elementary healthcare services.

The atom service of an agent may be a composite service of another agent because agents have varying degrees of knowledge about the basic services they can operate. For example, in a hospital, a health screening service can be considered as an atom service where all the examinations can be done in the hospital. However, it is a composite service in a clinic that contains sub services of blood testing and X-rays in different organizations.

Decomposition. Following some relationships in R, a service s can be decomposed into sub services (not necessarily atom services). The set of sub services is called a decomposition of s. A service may have different decompositions.

A service is achievable if (1) it can be decomposed into a set of atom services; and (2) the atom services are all available.

Example 1. Suppose in a health screening scenario,

$S = \{ s_1$ = "health screening,"
s_2 = "blood test,"
s_3 = "X-ray,"
s_4 = "blood test in ABC Lab,"
s_5 = "X-ray in ABC Lab,"
s_6 = "blood test in XYZ Lab" $\}$

$R = \{r_1: s_1 \rightarrow s_2, s_3,\quad r_2: s_2 \rightarrow s_4,\quad r_3: s_3 \rightarrow s_5,\ r_4: s_2 \rightarrow s_6\}$

Here, $\{s_2, s_3\}$, $\{s_4, s_3\}$, $\{s_4, s_5\}$, and $\{s_6, s_5\}$ are all decompositions of s_1. Service s_1 can be achieved by $\{ s_4, s_5\}$ or $\{ s_6, s_5\}$, i.e., for the health screening program, one solution is to do all the tests in ABC Lab; another solution is to do the blood test in XYZ Lab and the X-ray in ABC lab.

Property of Services. Several properties are associated with a service, such as price, waiting time, and facilities. Suppose we only consider the properties about which people are most commonly concerned. We define the property of a service s_i as a vector

$$p_i = [p_i^1, p_i^2, \ldots p_i^j \ldots p_i^k]$$

where k is the number of properties being considered and p_i^j is the value of the j-th property. For example, the property of service "blood test in ABC Lab" could be [\$210, 7 days, "no"], indicating that it costs \$210, takes 7 days to receive the result, and there is no anesthetic method. If the j th property is not applicable to a service, $p_i^j = 0$.

The property of services allows negotiators to make comparisons between services. However, there are often tradeoffs among the preferred properties, for example, the pathology collection center that has angel cream may be far away. People have to balance these tradeoffs to make a decision. We define the preference value of each service s_i using the common form of preference function:

$$Pr_i = \sum_{j=1}^{k} w_j \times p'^j_i \ ,$$

where Pr_i is the preference value of service s_i. Vector $W = [w_1, w_2, \ldots w_j \ldots , w_k]$ is the importance weightings on the k properties. $w_j \geq 0$ (j=1, 2, ..., k). Different parties may have different importance weightings. Vector $p'_i = [p'^1_i, p'^2_i, \ldots p'^j_i \ldots p'^k_i]$. p'^j_i is the normalized satisfaction scale of p_i^j, with values from 0 (not preferred) to 10 (very much preferred). If an agent wants to exclude services with certain property values, it can map those values to $-\infty$. For example, the cost of "\$10,000," "\$400," and "\$200" may be mapped to a scale of $-\infty$, 7, and 10 respectively, which shows that the negotiator is fully satisfied with \$200, satisfied with a cost of \$400, and will not consider a service cost of \$10,000. Another example is that the dental service properties "with happy gas (Nitrous Oxide)" and "without happy gas" may be rated as 9 and 5, respectively. It indicates that happy gas is highly preferred, but that the absence of happy gas is also acceptable. If the property is a continuous variable, the scale function will be continuous; if it is a discrete variable, the scale function will be discrete. We omit the details about the weightings and satisfaction scale functions.

Different parties have different importance weighting W and different satisfaction scale function M. They may also have different preference function F. The preference value of service s_i can be written as:

$$Pr_i = \begin{cases} -\infty \quad , & \textit{if service } s_i \textit{ is not available} \\ F(W, M(p_i)), & \text{otherwise} \end{cases}$$

Negotiators use the preference value to compare services.

In the knowledge base, if s_i is an atom service, p_i contains the actual values of all properties. If s_i is a composite service, it has different decompositions, and each decomposition may be related to different property values. We let p_i contain the estimated range of values for all properties. For continuous properties, we keep the value intervals as the estimation. For discrete properties, we keep the set of all possible values as the estimation. For example, in Example 1, suppose the concerned properties are “cost” and “whether or not it has angel cream,” p_4 = [\$180, “no”], p_6 = [\$200, “yes”]. p_2 should be the estimated cost range and estimated anesthetic methods of the “blood test” service. It could be [[\$180, \$200], {“yes,” “no”}] or [[\$150, +∞), {“yes,” “no”}].

Property $p_i^{\,j}$ with composite service s_i is not a vector of values, but is a vector of value ranges. We define its satisfaction scale $p'^{\,j}_i = M(p_i^{\,j})=\max\{M(v) \mid v \in p_i^{\,j}\}$, i.e., $p'^{\,j}_i$ is the highest satisfaction scale within the range. The estimated value ranges for composite services can be used as a heuristic in search algorithms. Choosing a better estimated value gives composite services more opportunities to be considered in the algorithm that we will introduce later.

Knowledge Graph. The knowledge base can be represented as an AND/OR graph, and is a hyper graph. Instead of arcs connecting pairs of nodes in the graph, hyper arcs connect a parent node with a set of successor nodes. These hyper arcs are called connectors. Suppose $KB = \langle S_{KB}, R, P\rangle$, and its graph representation is $G = (S_G, E, P)$, where

$S_G = S_{KB}$, i.e., nodes in G are the services in KB,

$E = \{(s_{i0}, \{s_{i1}, s_{i2}, \ldots s_{ik}\}) \mid s_{i0} \rightarrow s_{i1}, s_{i2}, \ldots s_{ik} \in R\}$, i.e. connectors in G are decomposition rules in KB.

Leaf nodes in G are atom services in KB. The knowledge graph of Example 1 is shown in Figure 1.

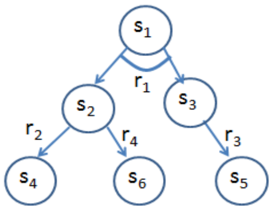
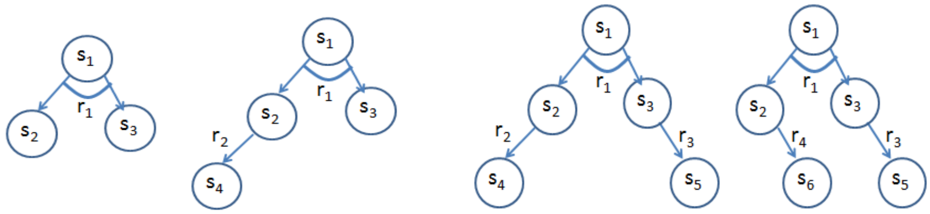


Figure 1. Knowledge graph

Solution Graph and Partial Solution Graph. In a knowledge graph G, a node s can be expanded to its successors by following exactly one connector. Each successor node can be expanded further in the same way, and a graph rooted on s will be generated. The graph is called a Partial Solution Graph of s. If all the leaves of the partial solution graph are the leaves of G, the partial solution graph is a solution graph. Partial solution graphs and solution graphs are graph representations of goal decompositions. Examples of partial solution graphs and solution graphs of the knowledge graph in Figure 1 are shown in Figure 2(a) and 2(b).



(a) (b)

Figure 2. (a) Partial solution graphs (b) Possible solution graphs

Suppose the knowledge base of an agent is maintained periodically so that it has no loop decomposition and the decompositions are all minimal. No loop decomposition requires that a service's decomposition cannot include the service itself. Minimal decomposition requires that the relationships will not produce unnecessary sub services. For example, if $\{s_1, s_2\}$ and $\{s_1, s_2, s_3\}$ are two of the decompositions of a service, then it does not meet the minimal decomposition requirement because s_3 is unnecessary.

4.3 Service Decomposition and Knowledge Combination

Many complex services have to be performed step by step. By decomposing a complex treatment goal into atom services, the agent builds its treatment plan. We developed an algorithm to decompose a service using a heuristic search strategy. Algorithm *Decomposition*, listed below, decomposes s_0 into atom services, based on Nilsson's AO* algorithm. During the process of creating a search graph and marking a partial solution graph, the algorithm gradually approaches the optimal solution by using the preference value of each service as heuristics. Different parties' preference values on the same service may be different because their importance weighting, satisfaction scale, and preference function are different.

The algorithm starts from s_0, and selects and marks the connector with the largest preference value as the temporary best solution for s_0. It then continues to decompose the sub services. Whenever there is new information that makes changes to the preference value of a service, the algorithm will propagate the newly discovered information up the service hierarchy, re-calculate the preference value, and make a new selection from among connectors.

Suppose that we have a knowledge base *KB*, an importance weighting vector *W*, a satisfaction scale function *M*, and a preference function *F*. The decomposition algorithm is as follows:

Algorithm 1. Decomposition (s_0)

1) Create a search graph G, G = { s_0 }
   If s_0 is an atom service, label s_0 as *Solved*. Calculate Pr_0.
2) Until s_0 is labeled as *Solved* , or $Pr_0 = -\infty$ do
   2.1) // Select node to expand
        Compute a partial solution graph H in G by tracking down marked connectors in G from s_0 (marks will be discussed later in this algorithm)
        Select any non-terminal leaf node s_n of H
   2.2) // Expand node s_n by generating its successors
        If $s_n \rightarrow s_1, s_2 \ldots s_k \in R$, Add all sub services of s_n to G
        For successors s_j not occurring in G, calculate Pr_j.

If s_j is leaf, label *Solved*.

2.3) // Propagate the newly discovered information up the graph

$C = \{ s_n\}$

Until C is empty, do

Remove a node s_m from C (s_m has no descendants in C)

For each connector $s_m \rightarrow s_{i1}, s_{i2},\ldots, s_{ik}$

$Pr_m^{\ i} = Pr_{i1} + Pr_{i2}+\ldots+ Pr_{ik}$

$Pr_m = \max_i (Pr_m^{\ i})$

Mark the best path out of s_m by marking one connector with the biggest $Pr_m^{\ i}$

If all nodes connected to s_m through this new marked connector have been labeled *solved*, label s_m *solved*

If s_m solved or Pr_m just changed, add all of the ancestors of s_m to C

3) If s_0 is labeled *Solved*, return *True*, else return *False*

End of Decomposition.

Upon receiving new knowledge from other agent(s), the agent will carry out a temporary knowledge base revision by adding the new knowledge to its existing knowledge base. The decision concerning whether or not to incorporate the new knowledge permanently in the knowledge base will be made by the agent through some other mechanisms. The temporary knowledge base revision can be implemented by the algorithm *Combination* listed below.

Here, we suppose the knowledge base of the agent is $KB=<S, R, P>$, and the agent will revise the KB to incorporate new knowledge noted as $KB'=< S', R', P' >$.

Algorithm 2. Combination ( )

For each new service in S', add into S

For each new relationship in R', add into R if it does not cause loop decomposition

For each new property p_n^{new}

If no property of s_n exists in KB, add p_n^{new} into P

If property p_n^{old} exists and $p_n^{old} \neq p_n^{new}$,

a. $p_n = p_n^{old} \cup p_n^{new}$

b. // Propagate the newly discovered information up the graph

$C=\{ s \mid s \text{ is the ancestor of } s_n\}$

Until C is empty, do

Remove a node s_m from C (s_m has no descendants in C)

For each connector $s_m \rightarrow s_{i1}, s_{i2},\ldots, s_{ik}$

$p_m^{\ i} = p_{i1} \oplus p_{i2} \oplus\ldots\oplus p_{ik}$

$p_m = \cup_i (p_m^{\ i})$

If p_m just changed, add all of the ancestors of s_m to C

c. If s_n is an atom in KB'

Add $s_n \rightarrow s_n'$ in KB, $p(s_n') = p_n^{new}$

If s_n is an atom in KB

Add $s_n \rightarrow s_n''$ in KB, $p(s_n'') = p_n^{old}$

End of Combination.

In the *Combination* algorithm, $p_m^{\ i}$ is obtained by applying the operator $\oplus$ on the property of its successors. The operator $\oplus$ is defined as follows: if the property holds a continuous value, add the value to obtain a value range; if the property holds a discrete value, calculate the union of the discrete sets. For example, [[\$100, \$200],{TV, Phone}] $\oplus$

[[\$110, \$150],{Phone, Internet}] = [[\$210, \$350],{TV, Phone, Internet}]; [[\$100, \$200],{Phone}] $\oplus$ [\$150, {Phone}] = [[\$250, \$350],{Phone}]. Then, p_m is assigned with the union (interval union for continuous value and set union for discrete value) of the properties of its decompositions. This ensures that the estimated property covers all the possible value ranges.

4.4 Negotiation Automation

With the above two algorithms, we can automate the main negotiation processes.

*Proposal generation***.** Assume a high level service that is defined as *s*. If algorithm *Decomposition* (*s*) returns *True*, the agent will propose the atom services in H as a treatment plan. The agent can provide graph H as the justification for the proposal.

*Cooperative-Competitive Solution Construction***.** When an agent receives a proposal for *s*, it will evaluate it and then decide whether to accept or deny it. If no agreement can be reached, the participating agents may consider exchanging related information, including information from the *KB* and the pursuing goals.

Upon receiving new knowledge, the agent will perform the algorithm *Combination* to combine the new knowledge into its knowledge base to form a temporary KB. Based on the newly built temporary knowledge base,

If *Decomposition* (s) =*True*

The atom services of H form the treatment plan

This solution is a cooperative solution because it is constructed based on both parties' knowledge. It is also a competitive solution because it selects the best preference value solution.

*Mutual Beneficial Solution Construction***.** If party A has goals s_A^1, s_A^2, …, s_A^s and party B has goals s_B^1, s_B^2, …, s_B^t, they want to seek some opportunities to achieve their mutual goals. We can add knowledge $s_{mutual} \rightarrow s_A^1, s_A^2, \ldots, s_A^s, s_B^1, s_B^2, \ldots, s_B^t$, into the knowledge base. If *Decompose* (s_{mutual}) is *True*, the partial solution graph H is the solution to s_{mutual}.

4.5 Correctness of the Method

If there is no treatment plan for s_0, i.e., all decompositions of *s* contain unavailable services or unwanted properties, according to the algorithm, Pr_0 will reach $-\infty$, so the algorithm returns false.

If there is a treatment plan from s_0 to a set of atom services, and if for all service decomposition relationships $s_n \rightarrow s_1, s_2 \ldots s_k$, $Pr_n \geq Pr_1 + Pr_2 + \ldots + Pr_k$, (i.e. $p_n \supseteq p_1 \oplus p_2 \oplus \ldots \oplus p_k$), the algorithm will terminate and return True. By tracing the marks, graph H is the optimal solution.

Hence, with the restriction $p_n \supseteq p_1 \oplus p_2 \oplus \ldots \oplus p_k$, the algorithm is able to find the optimal solution. By limiting the estimated property of a service to be not worse than the actual property, the descendants of this service will have the opportunity to be explored. However, if the estimated property is significantly better than the actual property, this will direct the algorithm to spend time to explore this seemingly optimal, but actually not optimal, branch. In the worst case, the algorithm has exponential time complexity as it may explore all of the options. Hence, a good estimation will reduce the unnecessary search required to find the optimal solution.

5 Example

We illustrate the negotiation strategy and algorithms in Section 4 using an example.

Frank is a 70 year-old retired university professor who smokes and was diagnosed with Type II Diabetes (non-insulin dependent diabetes) many years ago. One day, he fell and broke his leg, and his wife Rose sent him to a hospital.

Patients with diabetes have an increased risk of complications, such as poor wound healing, infection, electrolyte imbalance, and diabetic ketoacidosis. Blood tests are needed to monitor the blood glucose levels on the day before surgery and/or on the day of surgery. Patients with known underlying pulmonary disease or risk factors, such as smoking, should have routine chest X-rays before surgery. Therefore, a chest X-ray and blood test are required before Frank's leg operation. With the help of a hospital agent, Dr. Edmond will propose a treatment plan for Frank.

For simplicity of presentation, we define some symbols to represent the services. Suppose

s_0 : Frank's treatment
s_1 : Preoperative evaluation
s_2 : Severe fracture treatment
s_3: Chest X-ray
s_4 : Blood test
s_5 : X-ray in the hospital radiology department
s_6 : Blood test in the hospital pathology department
s_7 : Standard fracture treatment process (including an operation and 5 days recovery in hospital ward)
s_8 : Emergency fracture treatment process (an operation in the hospital and discharge to other healthcare centers)
s_9: Operation in the hospital
s_{10}: Recovery
s_{11}: Recovery in Healthcare Center A
s_{12}: Recovery in Healthcare Center B
s_{13}: Existing latest X-ray
s_{14}: Recovery in Aged Care Center

Suppose the hospital agent has the knowledge base $KB_H = <S_H, R_H, P_H>$, where

$S_H = \{ s_0, s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8, s_9, s_{10}, s_{11}, s_{12}\}$

$R_H = \{ s_0 \rightarrow s_1, s_2;$ $\quad s_1 \rightarrow s_3, s_4;$
$s_3 \rightarrow s_5;$ $\quad s_4 \rightarrow s_6;$
$s_2 \rightarrow s_7;$ $\quad s_2 \rightarrow s_8;$
$s_8 \rightarrow s_9, s_{10};$ $\quad s_{10} \rightarrow s_{11};$
$s_{10} \rightarrow s_{12}; \}$

$P_H = \{p_0$= [\$8300, {TV, Phone, Internet}] ;
p_1=[\$300, 0] ;
p_2= [\$8000, {TV, Phone, Internet}] ;
p_3=[\$300, 0];
p_4= [0, 0];
p_5=[\$300, 0];
p_6= [0, 0];

p_7=[\$16,000, {TV, Phone, Internet}] ;
p_8=[\$8,000, {TV, Phone}] ;
p_9=[\$6,000, 0] ;
p_{10}=[\$3,000, {TV, Phone}] ;
p_{11}=[\$3,000, {Phone}] ;
p_{12}=[\$4,000, {TV, Phone}] ;
}

For simplicity, this example considers only the "cost" and "facilities in ward" properties. Instead of using an interval for cost, we assume that everyone prefers a lower cost, so we only record the lower limit of the interval. The hospital agent's knowledge graph is shown in Figure 3. For ease of reading, we put the lowest cost instead of the cost range beside each node.

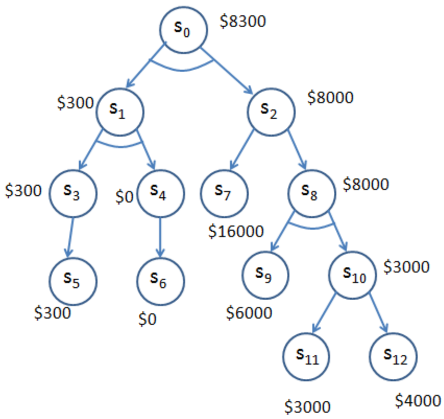


Figure 3. Hospital agent's knowledge graph

The overall service of the hospital is s_0. Without any special preference, the hospital agent proposes a treatment plan, including $\{s_5, s_6, s_7\}$, as indicated in Figure 4. Instead of the preference value, we put the cost beside each node for easy reference. The total cost in this case is \$16300. The plan is to have an X-ray and blood test in the hospital, then follow the standard process to have a leg operation, followed by a 5-day stay in the hospital ward.

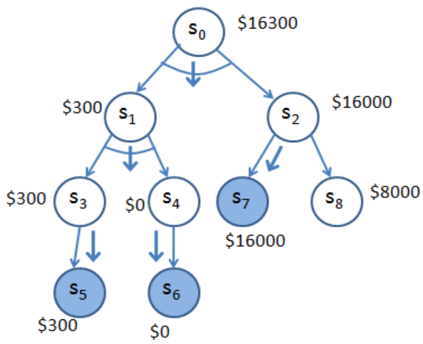


Figure 4. Hospital agent's treatment plan

Position-Based Negotiation. Frank does not want to stay in the hospital ward because it is expensive. Frank rejects this plan and proposes Healthcare Center C for his recovery, but the hospital has no direct collaboration with Healthcare Center C. The discharging of patients to Healthcare Center C is troublesome, so the hospital rejects Frank's proposal. In this case, Frank has to accept the hospital's proposal, but he is not satisfied with the treatment plan.

Interest-Based Negotiation. The hospital agent challenges Frank's proposal by asking for his reasons. Frank explains that Healthcare Center C is inexpensive. Considering "cost" in the property, the hospital agent comes up with the cheapest plan, including $\{s_5, s_6, s_9, s_{11}\}$, that is required to do the operation in the hospital, then to transfer to Healthcare Center A for recovery. The total cost is \$9300. The solution graph is illustrated in Figure 5. The estimated cost \$8000 of s_8 is replaced by the actual cost \$9000. The new plan meets the hospital's goal to treat Frank's leg and also satisfies Frank's criterion to be less costly.

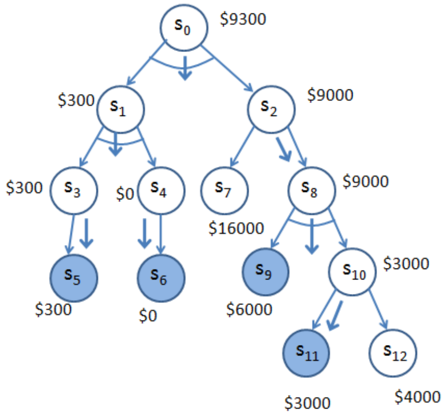


Figure 5. Hospital agent's cheap treatment plan

Cooperative-Competitive Negotiation. After the hospital agent proposes the treatment plan, Frank's family doctor agent and the other healthcare provider's agent meet to improve the plan. Frank's family doctor agent contributes knowledge $\{s_3 \rightarrow s_{13}\}$ to tell the hospital that Frank can use his X-ray taken 3 days ago (the additional cost is \$0). A newly set-up Aged Care Center provides information $\{s_{10} \rightarrow s_{14}\}$, by informing the other agents that Frank can recover in the Aged Care Center, which costs \$3000 and which has {TV, Phone, Internet}. The hospital agent combines the new knowledge and develops a temporary knowledge graph. In this case, the agent considers the cost property and the ward facility property, because Frank prefers to have a cheap ward with an Internet connection. The proposal is illustrated in Figure 6. Healthcare Center A and the Aged Care Center both have the same price, but the Aged Care Center has an Internet connection, so it receives a higher preference value. Hence, the Aged Care Center is selected. Now, Frank is very happy with the services he has received. The total cost is reduced to \$9000 and includes better facilities (Internet).

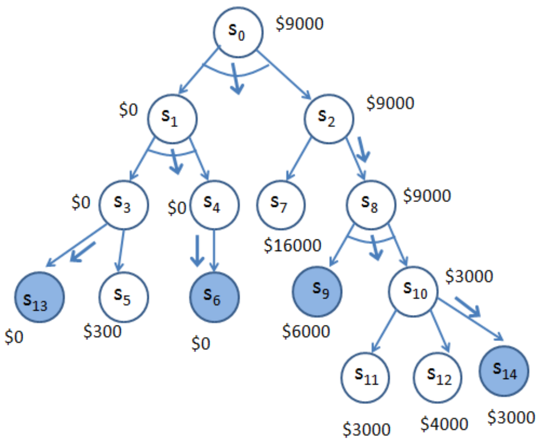


Figure 6. Hospital agent's cooperative-competitive plan

6 Conclusion

Negotiation widely exists in the healthcare domain between service providers (general practitioners, specialists, laboratory clinicians, etc.) and patients. Negotiation in the healthcare environment is different from that in other areas where the negotiators usually have conflicting goals (e.g., the buyers want to reduce the price and the sellers want to raise the price). The negotiations between healthcare professionals and patients usually aim to reach the same goal, which is to arrive at the best treatment plan for the patients. Hence, we need new strategies for healthcare service negotiation. This paper proposes a new cooperative-competitive negotiation model that allows involved parties to analyze the higher level goals behind their positions and use shared knowledge to construct solutions. It has the following advantages:

– Pursuing alternative solutions or altering desired goals when there is no agreement on the initial negotiation positions. This enables the healthcare professionals to explore more options.

– Reaching cooperative solutions that are based on the expertise of different professionals. This promotes collaborative decision making.

– Selecting optimal solutions from among competitive options. That is, it always tries to find a treatment plan that is most appropriate to the patient.

– Seeking mutually beneficial solutions by considering a joint goal. This requires the participation of the patients in their own health management planning and achieves patient-centered care.

The paper also presents computational methods to automate the negotiation process. This negotiation strategy is more powerful and constructive than traditional strategies, especially in domains that involve multiparty collaboration, such as healthcare.