Argumentation graphs with constraint-based reasoning for collaborative expertise

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HIGHLIGHTS

- Reasoning underlying the remote collaborative processes in complex decision making.
- Abstract argumentation framework with the directed graphs to represent propositions
- Conceptual graphs for ontological knowledge modelling and formal visual reasoning.
- Competencies and information sources for the weighting of shared advices/opinions.
- Constraints checking for conflicts detection according to medical–legal obligations.

ABSTRACT

Collaborative processes are very important in telemedicine domain since they allow for making right decisions in complex situations with multidisciplinary staff. When modelling these collaborative processes, some inconsistencies can appear. In semantic modelling (conceptual graphs), these inconsistencies are verified using constraints. In this work, collaborative processes are represented using an argumentation system modelled in a conceptual graph formalism where inconsistencies could be particular bad attack relation between arguments. To overcome these inconsistencies, two solutions are proposed. The first one is to weight the arguments evolving in the argumentation system on the basis of the competencies of the health professionals and the credibility of the sources justifying their advice (arguments), and the second one is to model some law concepts as constraints in order to check their compliance of the collaborative process.

Keywords:
Argumentation theory
Decision making
Conceptual graphs
Inconsistencies
Weighting
Medical deontology

1. Introduction

Conceptual graphs introduced by [1] have been used in several works for knowledge representation, modelling and visualisation. Very often, the knowledge base building process can lead to inconsistencies. To overcome these issues, *constraints* can be used and applied to the concerning knowledge base.

An effective integration of constraints in collaborative processes must therefore become a central feature of consistent development efforts in argumentative reasoning. In fact, in our previous works [2–4], we have modelled collaborative processes between medical professionals by using argumentation [5] and conceptual graphs. In these previous works, we did not take into consideration the notion of *constraints* which is essential in medicine. Indeed, in situations where consents must be given such as medical procedures, patients and other subjects have to deal with constraints [6]. These constraints defined in [6] are categorised as *information constraints* and they are in number of three [6]: (i) constraints from the concept of a disease, (ii) constraints from the diffusion of medical innovation, (iii) constraints from withholding information. These are few examples of constraints in the medical domain.

We have noticed that during collaborative medical processes modelled with the Dung argumentation system [2,4] inconsistencies can appear (for example bad attack relation due to the non-compliance with medical deontology concepts or arguments given by a medical professional that should not attack another argument). Given that the collaborative processes are modelled

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using the Dung argumentation framework, itself represented in conceptual graph formalism which can support the expression of semantic constraints in order to check if there are inconsistencies or not. The solution proposed in this work is to use some laws governing remote medical collaboration that will be modelled as constraints because the laws are obligations and must be respected. Moreover, given that in collaborative medical processes the stakeholders give some advice, the line of reasoning is to weight pieces of advice and then use these weighted pieces of advice as constraints. In our work, the bad attacks represent the attack that starts from one argument to another with greater weight or attacks that do not comply with the guidelines of medical deontology. The detected bad attacks are ignored or removed from the graph of attacks [7,8], then the acceptability semantics are computed on the remaining attacks by using the algorithms proposed in [3].

The challenge in this paper is to model these constraints in conceptual graphs formalism in a real case study of remote collaboration between medical professionals. The novelty in this work is the fact of combining argumentation and conceptual graphs while taking in consideration *constraints*; the whole applied to remote medical practice such as teleexpertise which is a medical practice that involves at least two medical professionals who collaborate by sharing patients' information and experiences aimed at managing (diagnosis and treatments) a patient. The advantage of our solution is to bring assistive tools to judicial experts in case of litigation after an act of teleexpertise while providing consistent collaborations between remote medical professionals.

In the coming sections, we will recall some basic notions of conceptual graphs and constraints, talk about some related works and by a case study we will propose a modelling of some constraints directly in CoGui software[1] [9]. We end this paper by a results and discussions section and a conclusion section.

2. Background

2.1. Argumentation framework

Given that we are dealing with Dung argumentation framework [5], a brief explanation of the generalities of the concepts that we are going to refer to in this paper will permit better understanding of our proposal.

Definition 1. An argumentation framework is a couple $F = (\mathcal{A}, \mathcal{R})$, where $\mathcal{A}$ is a set of arguments and $\mathcal{R} \subseteq \mathcal{A} \times \mathcal{A}$ is the attack relation. The couple $(a, b) \in \mathcal{R}$ means that a attacks b. It is said that an argument $a \in \mathcal{A}$ is defended (in F) by a set $S \subseteq \mathcal{A}$ if, $\forall\, b \in \mathcal{A}$ such that $(b, a) \in \mathcal{R}$, $\exists\, c \in S$ such that $(c, b) \in \mathcal{R}$.

Example 1. Let $AF = (\mathcal{A}, \mathcal{R})$ be an argumentation framework with $\mathcal{A} = \{a, b, c, d, e\}$ and $\mathcal{R} = \{(a, b), (a, c), (a, d), (b, a), (c, a), (e, a)\}$. Graphically AF is represented by Fig. 1 depicting a graph of attacks.

In argumentation framework, it is important to remember that there exist some key concepts helping in the decision-making process. These concepts are: **conflict-free sets**, **acceptability semantics** and **arguments status** [5].

Definition 2. Conflict-free set.
Let $AF = (\mathcal{A}, \mathcal{R})$ be an argumentation framework and $\mathcal{B} \subseteq \mathcal{A}$. $\mathcal{B}$ is conflict-free if there are no $\alpha, \beta \in \mathcal{B}$ such that $(\alpha, \beta) \in \mathcal{R}$.

Example 2. Referring to Fig. 1, {d,e} is conflict-free while {a,b,c} is not.

[1] Conceptual Graphs Graphical User Interface.

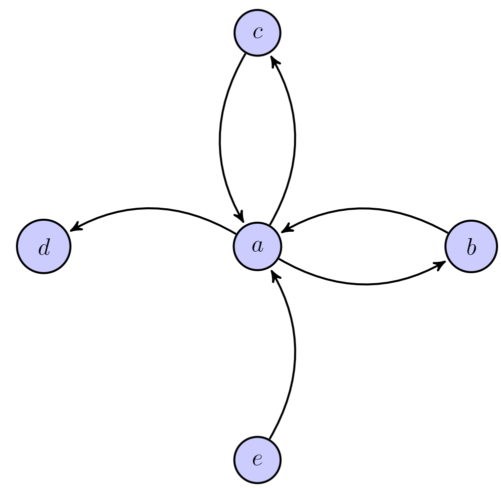


Fig. 1. Graph of attacks.

Definition 3. Acceptability semantics.
Let $AF = (\mathcal{A}, \mathcal{R})$ be an argumentation framework and $\mathcal{B} \subseteq \mathcal{A}$ a conflict-free set.

- $\mathcal{B}$ is an admissible extension iff it defends any element in $\mathcal{B}$.
- $\mathcal{B}$ is a preferred extension iff $\mathcal{B}$ is a maximal (w.r.t. set $\subseteq$) admissible set.
- $\mathcal{B}$ is a stable extension iff $\forall\ a \in \mathcal{A} \setminus \mathcal{B}, \exists\ b \in \mathcal{B}$ such that $(a, b) \in \mathcal{R}$.
- $\mathcal{B}$ is a complete extension iff $\mathcal{B}$ is admissible and $\forall\, a \in \mathcal{A}$, if a is acceptable compared to $\mathcal{B}$, then $a \in \mathcal{B}$.
- $\mathcal{B}$ is a grounded extension iff $\mathcal{B}$ is complete and $\nexists\, \mathcal{C}$ such that $\mathcal{C} \subset \mathcal{B}$.

Example 3. Referring to Fig. 1:

- Admissible extensions: $\{\emptyset\}$, $\{e\}$, $\{d, e\}$, $\{b\}$, $\{b, d\}$, $\{b, e\}$, $\{b, d, e\}$, $\{c\}$, $\{b, c\}$, $\{c, d\}$, $\{b, c, d\}$, $\{c, e\}$, $\{b, c, e\}$, $\{c, d, e\}$, $\{b, c, d, e\}$.
- Preferred extension: $\{b, c, d, e\}$.

Property 1. *Arguments status*
Let $AF = (\mathcal{A}, \mathcal{R})$ be an argumentation framework and $\varepsilon_1, \ldots, \varepsilon_n$ its extensions under a given semantics. Let $a \in \mathcal{A}$.

- *a is skeptically accepted iff $a \in \bigcap_1^n \varepsilon_i$.*
- *a is credulously accepted iff $\exists\, \varepsilon_i$, such that $a \in \varepsilon_i$.*
- *a is rejected iff $a \notin \bigcup_1^n \varepsilon_i$.*

2.2. Conceptual graphs, projection operation and constraints

In this section, we will recall the background of conceptual graphs and constraints drawn from [10]. The argumentation system [5] used in this work is well explained in our previous works [2–4,11].

2.2.1. Conceptual graphs

Conceptual graphs have been introduced by [1] in 1984. It is a formalism for knowledge representation and reasoning. A conceptual graph is a bipartite oriented graph:

- Bipartite: two kinds of nodes: **concepts** and **relations**;
- Nodes are linked by oriented arcs or numbered arcs;
- An arc always links a concept to a relation;
- A concept node can be isolated (not linked).

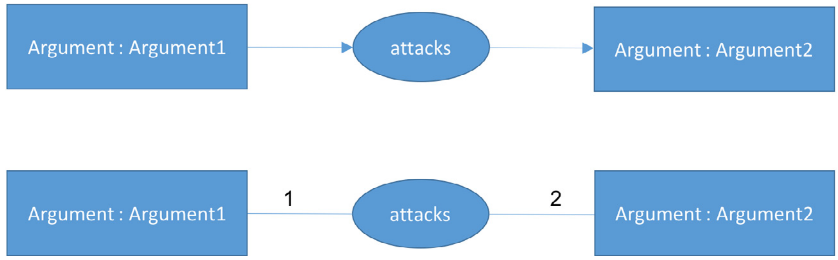


Fig. 2. Two possible representations of conceptual graph.

The formal definition of conceptual is given below (Definition 5). Before that a definition of a vocabulary (Definition 4) is given because, it provides the interpretations of some basic notions which are used to construct Definition 5 and make it easier to be understood.

Definition 4 (*Vocabulary*). A $\mathcal{BG}$ vocabulary is a triple $(T_C, T_R, \mathcal{I})$ where:

- T_C and T_R are finite pairwise disjoints sets.
- T_C, the set of concept types, is partially ordered by a relation $\leq$ and has a greatest element denoted $\top$.
- T_R, the set of relations symbols, is partially ordered by a relation $\leq$, and is partitioned into subsets $T_R^1, \ldots, T_R^k$ of relation symbols of arity $1, \ldots, k$, respectively. The arity of a relation r is denoted arity(r). Any two relations with different arities are not comparable.
- $\mathcal{I}$ is the set of individual markers, which is disjoint from T_C and T_R. Furthermore, $*$ denotes the generic marker, $\mathcal{M} = \mathcal{I} \bigcup \{*\}$ denotes the set of markers and $\mathcal{M}$ is ordered as follows: $*$ is greater than any element in $\mathcal{I}$ and are pairwise incomparable.

Definition 5 (*Basic Conceptual Graph*). A basic conceptual graph ($\mathcal{BG}$) defined over a vocabulary $\mathcal{V} = T_C, T_R, \mathcal{I}$, is a 4-tuple $\mathcal{G} = (C, R, E, l)$ satisfying the following conditions:

- (C, R, E, l) is a finite, undirected and bipartite multigraph called the underlying graph of $\mathcal{G}$, denoted graph($\mathcal{G}$). C is the concept node set, R is the relation node set (the node set of $\mathcal{G}$ is $N = C \bigcup R$). E is the family of edges.
- l is a labelling function of the nodes and edges of graph($\mathcal{G}$) that satisfies:
  1. A concept node c is labelled by a pair (type(c), marker(c)), where type(c) $\in T_c$ and marker(c) $\in \mathcal{I} \bigcup \{*\}$,
  2. A relation node is labelled by $l(r) \in T_R$. $l(r)$ is also called the type of r and is denoted by type(r),
  3. The degree of a relation node r is equal to the arity of type(r),
  4. Edges incident to a relation node r are totally ordered and they are labelled from 1 to arity(type(r)).

The Fig. 2 depicts an example of conceptual graph. In the second representation, the values 1 and 2 represent the orientation of the attack relation (for example the second representation means that *Argument1 attacks Argument2*). In Fig. 2, *Argument1* and *Argument2* are instantiations (individuals) of the concept *Argument* and *attacks* is a *Relation*.

2.2.2. Conceptual graph operation: projection

The knowledge in conceptual graph is represented by labelled graphs (Basic graphs $\mathcal{BG}$) and the reasoning process is based on a graph operation called homomorphism [10]. The projection allows for defining specialisation between two graphs. It looks for a request graph $\mathcal{G}$ in context graph $\mathcal{H}$. Intuitively, when a projection exists from $\mathcal{G}$ to $\mathcal{H}$, it means that the knowledge represented by $\mathcal{G}$ is contained in (or implied by) the knowledge represented by $\mathcal{H}$. As said above, the mechanism of projection is a global view of a specialisation operation sequence that is graphically and logically defined in [12]. The reasoning processes based on projection are logically founded since the projection itself is well-founded and complete with respect to the deduction in first-order logic [10].

Formally, a homomorphism is defined as follows:

Definition 6 (*$\mathcal{BG}$ Homomorphism*). Let $\mathcal{G}$ and $\mathcal{H}$ be two $\mathcal{BG}$s defined over the same vocabulary. A homomorphism π from $\mathcal{G}$ to $\mathcal{H}$ is a mapping from $C_{\mathcal{G}}$ to $C_{\mathcal{H}}$ and from $R_{\mathcal{G}}$ to $R_{\mathcal{H}}$, which preserves edges and may decrease concept and relation labels, that is:

- $\forall (r, i, c) \in \mathcal{G},\ (\pi(r), i, \pi(c)) \in \mathcal{H}$,
- $\forall e \in C_{\mathcal{G}} \bigcup R_{\mathcal{G}}, l_{\mathcal{H}}(\pi(e)) \leq l_{\mathcal{G}}(\pi(e))$.

The Fig. 3 depicts an illustration of a projection mechanism. This illustration gives an answer to the question depicted in the request graph. Indeed, the request graph expresses the following question: "*Is there any medical professional who gives any argument?*". This means the search looks anywhere in the context graph for the requested response and the projection finds the following answer: "*the ophthalmologist gives argument beta*".

2.2.3. Constraints

The constraints are used to validate a knowledge base according to some specifications (or recommendations) such as laws and skills [10]. In a knowledge base, it is the *facts* that are checked with the constraints. A constraint is formed in conceptual graph formalism by a conditional part and mandatory part [13]. There exists two types of constraints [10]:

- **Positive constraints**: expresses a property such as "if *A* holds so must *B*".
- **Negative constraints**: expresses a property such as "if *A* holds, *B* must not".

Definition 7 (*Constraints*). A positive (resp. negative) constraint C is a bicoloured Basic Graph ($\mathcal{BG}$). $C_{(0)}$, the subgraph induced by the nodes of colour 0, is called the condition of constraint, $C_{(1)}$, the subgraph induced by the nodes of colour 1 and the frontier nodes, is called its obligation (resp. interdiction). A $\mathcal{BG}$ G satisfies a positive (resp. negative) constraint C if every (resp. no) homomorphism from the condition of C to the irredundant form of a graph G (resp. to G) can be extended to a homomorphism from C as whole. A $\mathcal{BG}$ π-violates a positive (resp. negative) constraint C if π is a homomorphism from the condition C to the irredundant form of G (resp. to G) that cannot be extended (resp. that can be extended) to a homomorphism from C as whole. G violates C if it π-violates C for some homomorphism π, in other words G does not satisfy C.

For the negative constraints, the mapping between consistency and logical deduction is obvious and is based on correspondence soundness and completeness with respect to a formal semantics.

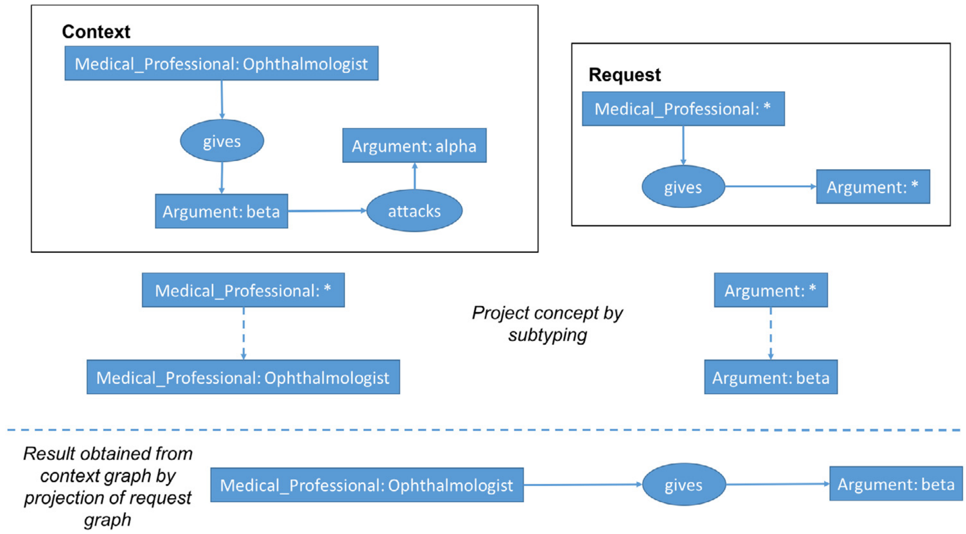
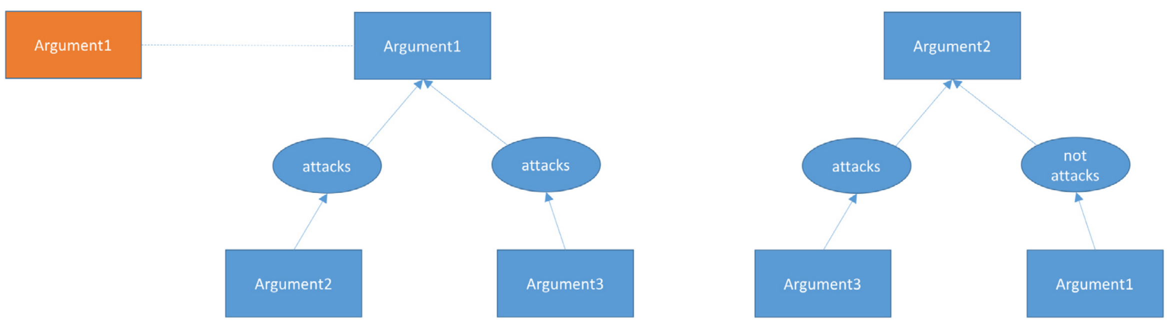


Fig. 3. Illustration of a projection mechanism.



(a) Positive constraint.

(b) Negative constraint.

Fig. 4. Constraints expressed in conceptual graph formalism.

Therefore, a negative constraint is violated by a fact if and only if there is the same violation between the logical formulas underlying the graph-based representation of the fact and the constraints [10].

The Fig. 4a and the Fig. 4b depict some examples of constraints modelled in conceptual graph formalism.

In these examples, we consider a collaboration between a **nurse**, an **attendant (family doctor)** and a **Geriatrician**.

- Argument1: argument of the Nurse;
- Argument2: argument of the Attendant;
- Argument3: argument of the Geriatrician.

Positive constraint: Any argument provided by the Nurse must be attacked.

Negative constraint: Any argument of the Attendant attacked by an argument of the Geriatrician must not be attacked by an argument of the Nurse.

The idea is to use constraints for detecting bad attacks, in other words attacks that fail. With regard to the Nurse, it is just a given example to illustrate how to express constraints. Under practical conditions, concerning the relationship between Physicians and Nurses, the negative constraints may rise from a nurse within the limits of her knowledge or experience gained during her practice would be to not implement the instructions if the patient's life is put in danger outside a pre-defined palliative care of the patient or if it is judged that the doctor obstructs the rules of ethics in an ostentatious manner. The constraint coming from the nurse would more likely be a negative constraint. A positive, though fair, constraint can only be a suggestion that the physician may or may not consider by integrating it into the context (time, place, clinical condition of the patient) as it will be legally solely responsible for the medical decision to take, which can be made to be dynamic.

Constraints are used in this work to verify a-posteriori the obtained graphs of attacks. To our knowledge, there are some works that integrate constraints directly in the argumentation systems definition [14] offering less flexibility for their modifications. In reality, one should give the opportunity to modify the constraints dynamically regarding practical realities. To do this, we found useful to include the constraints a-posteriori in the argumentation framework. Our constraints are semantically well defined in conceptual graph formalism and the verification mechanisms of their compliance are based on a graph operation called projection. The projection allows for defining a generalisation/specialisation relation over conceptual graphs.

3. Materials

Argumentation (Dung style [5]) has been used in many works for collaborative decision-making process. The works of [3,2] deal about it. The major difference between these works and this one is that in the present work we take into account the weight of the arguments evolving in the argumentation system.

Several works coupling argumentation and constraints have been identified in the literature. For example, *Bourguet* [15] defines some constraints in conceptual graph formalism over an argumentation system. In his work, he used constraints to formalise some properties of the argumentation system. He focuses his work only on negative constraints and does not show how the constraints are applied on the graph of attacks of the argumentation system. This is one main difference with our proposal in which we take into account constraints in order to refine a graph of attacks according to some specifications (or recommendations) such as laws and skills. In addition, one major difference with his proposal (extensions are generated in declarative and semi-declarative manner) is our proposal to engage efficient algorithms and visual operations of conceptual graphs for acceptability semantics generation [3].

In [14], the authors proposed a new argumentation system framework (an extension of Dung argumentation system [5]) taking into account directly the notion of constraints in the definition of the argumentation system. For us, it is a kind of a-priori process which is not very dynamic. In fact, when constraints change, one has to redefine the entire argumentation system unlike our solution wherein changing some constraints has no incidents on the defined argumentation. In addition, their approach does not take in consideration the modelling in conceptual graph formalism.

The authors of [16] proposed a work combining argumentation and constraints, but in their work, they used constraints to find the semantics of acceptability of the argumentation system. Their method is to transform the Dung argumentation system into constrained argumentation system and then to generate extensions as CSP (Constraint Satisfaction Problem) solutions. In our proposal, we used a formal method relying on some specified properties and definitions to build extensions. Based on these properties and definitions, we proposed algorithms for conceptual graphs handling and the generation of extensions [3].

Given that, we are dealing with the weight of arguments in the argumentation system, it is then important to recall some works treating this concept. In fact, the notion of weight in argumentation systems has been introduced in [17] for solving inconsistency problems in artificial intelligence. In their proposal, it is the attacks that are associated with a weight while in ours it is the arguments that are associated with a weight. We chose to weigh the arguments instead of the attacks because of the conceptual graphs modelling. Indeed, in the conceptual graphs formalism, **argument** and **weight** are represented as *concepts* and **attacks** are represented as *relations* linking two arguments. Thus, it is possible to easily assign a weight to an argument by creating a *relation* between a *concept* **argument** and a *concept* **weight**.

The strength of arguments is also evaluated using an extension of Dung argumentation framework called Preference-based Argumentation Framework [18]. The idea behind such framework is to introduce the notion of preference in the argumentation system. In other words, an attack is ignored (removed) when an attacked argument is preferred or stronger than its attacker, the semantics computing is then applied on the remaining attacks [19,20]. We reuse this idea in this paper, but in addition we give a method for the weighting of arguments in collaborative medical expertise.

In our previous works, we modelled remote medical collaborative processes (teleexpertise) by using the Dung argumentation framework the whole represented in conceptual graphs formalism [2,3]. In these works, algorithms for building acceptability semantics over conceptual graphs have been proposed which is a value added to deal with conceptual graphs and argumentation. In the model proposed in these works, the arguments provided by the different medical professionals are collected by a server in order to automatically compute acceptable arguments under the preferred semantics which is always defined for any argumentation framework [5]. The collected arguments have the same force, in other words, the same weight; which is not the case in real life due to the level of expertise of the involved medical professionals and the sources of information used to justify their arguments. Moreover, the teleexpertise is also guided by the guidelines of medical deontology to comply. In conceptual graphs these notions (weighted arguments, medical deontology compliance) can be verified by using constraints. So, in this case, these constraints allow for the extension of our previous works. The constraints will thus offer an adequate framework for arguments weights integration (regarding the credibility of sources and the actors' level of competency) during collaborative activities.

The reasoning approach of this work is to firstly build an argumentation system according to the arguments provided by the different medical professionals and secondly to check the consistency of this argumentation system. The inconsistency checking consists of finding bad attack relations that should exist. The bad attack relation identified will be deleted from the argumentation system. At the end of the checking process, if an argument is isolated, it must be deleted from the argumentation system: so that we finally obtain a consistent argumentation system (without bad attack relations and isolated arguments) on which will be applied the algorithms to find the acceptable arguments.

4. Methods

4.1. Weighting the arguments of the medical professionals

Generally, the stakeholders involved in a practice of the teleexpertise are expert in their field, so when a medical professional wants to be an expert, his skills (competencies) are evaluated. When his skills meet the requirements, he is now considered as an expert. The competencies are declined into six core competencies [21]:

1. Medical knowledge;
2. Patient Care;
3. Professionalism;
4. Interpersonal Communication;
5. Practice-based Learning: personal improvement;
6. System-based Practice: system improvement.

There are five levels [22] to be reached by a physician in order to be considered as an expert:

- **Novice**: In this level, a health professional can execute assigned tasks but needs some helps such as policy for patient care and local medical protocols.
- **Advanced Beginner**: In this level, a health professional can manage in time assigned tasks in compliance with local practice and/or policy, but still needs some help in unfamiliar situations.
- **Competent**: In this level, a health professional can manage in time assigned tasks, more he can identify and seek solutions for unfamiliar circumstances.
- **Proficient**: In this level, a health professional can handle multiple tasks. He can find appropriate solutions in difficult situations, and sometimes be contacted by his peers for providing them guidance.
- **Expert**: When the top level (level 5) is reached by a physician, one can assume that: "he is now able to handle multiple tasks in complex circumstances and can be a reference for his peers for support in difficult or unfamiliar circumstances" [22].

In this work, the weighting of the arguments takes into consideration both competencies (competencies are modelled as levels of expectation) and the sources used to support the advice of the medical professionals involved in an act of teleexpertise [4]. Several works have been achieved in weighting competencies, we can cite for example [23–25]. Different methods can be used for competency weighting: as illustration, we have fuzzy models [23], belief functions [26].

We assume that the weight of an argument is a function of the level (l) of the physician and the sources (s). Thus, the more the level of a physician moves towards the top level and his sources of information are relevant the more the weight of his argument is high.

$$\mathcal{W}_A = f(l, s) = \frac{\alpha \mathcal{W}_l + \beta \mathcal{W}_s}{\alpha + \beta}, \text{ with } \alpha, \beta \in]0, 1] \tag{4.1}$$

In Eq. (4.1), W_A represents the weight of an argument, l and s respectively the competence level and the sources.

- $\mathcal{W}_l$: represents the weight of the medical professional's level of competence. There are five levels of competence then it is easy to weight them:
  - **Novice**: weight = 0.2;
  - **Advanced Beginner**: weight = 0.4;
  - **Competent**: weight = 0.6;
  - **Proficient**: weight = 0.8;
  - **Expert**: weight = 1.
- $\mathcal{W}_s$: represents the weight of the sources of information. According to the following sources of information a weighting method is applied:
  - medical information on the Internet (use of methods for assessing the quality of health information on the Internet such as NetScoring [27,28], Health on the Net[2]),
  - medical articles in journals ($\mathcal{W}_s = \frac{\text{impact factor}}{\max(\text{Existing impact factor})}$),
  - medical books (known editor $\mathcal{W}_s = 1$, unknown editor $\mathcal{W}_s = 0.5$),
  - past experiences based on similar cases [29]. In this situation, the similarity measure [30] can be used for weighting of past experiences which are stored into a knowledge base. A small section will be dedicated to explain how past experiences are weighted.

4.2. Weighting past experiences

The experiences are founded on similar cases where similarity can be measured. The similarity measure is based on the exploitation of the full taxonomy knowledge of an ontology by taking into consideration the number of differences between the superconcepts (i.e. ancestors or subsumers of a concept) for a couple of concepts (C) [29]. The similarity measure will allow for showing if the current case is similar to the past ones and gives a distance of similarity that will be used in the weighting process of the past experiences. The similarity measure is expressed as follows:

$$sim(C_1, C_2) = -\log_2 \times \frac{|T(C_1) \cup T(C_2)| - |T(C_1) \cap T(C_2)|}{|T(C_1) \cup T(C_2)|}$$

- $T(C_i) = \{C_j \in C, C_j \text{ is the superconcept of } C_i\} \cup \{C_i\}$
- C_1 is a concept from the past case,
- C_2 is a concept from the current case,
- $|T(C_1) \cup T(C_2)|$ is the total number of superconcepts between the two compared concepts,
- $|T(C_1) \cap T(C_2)|$ is the total number of shared superconcepts between the two compared concepts.

This similarity measure takes a value of the similarity only between two concepts. However, like the work achieved in [29] we are interested in experiences described by descriptors. In [29], the authors represent an experience as a triplet $E_i = \langle C_i, A_i, Si \rangle$, where C_i, A_i and Si are respectively the context (description of the problem), analysis (a search for the main cause of the problem), solution (how the problem is solved). Regarding their work, we represent an experience as a collection of information incorporating:

- context (description of the clinical problem),
- diagnosis (finding the root causes of the disease),
- treatment (set of medical actions for treating the patient).

Thus, we formally represent an experience as a triplet $E_i = \langle C_i, D_i, Ti \rangle$, where C_i, D_i and Ti are respectively the context, diagnosis and treatment. For computing the similarity measure, we will reuse the work achieved in [29], where the measure of similarity consists of computing local similarities which is the combination of presence checking, taxonomy similarity and comparison of functional condition or safety levels. This similarity measure is applied between the source case and the target case in a descriptor j:

$$M_{Sim_{ij}} = \varphi_{ij}^{Presence} * \varphi_{ij}^{Value} * \varphi_{ij}^{State}$$

- **Presence**:
$$\begin{cases} \varphi_{ij}^{Presence} = 1 \text{ if the past experience (case) and the current case contain the descriptor.} \\ \varphi_{ij}^{Presence} = 0 \text{ if the descriptor is not specified in the past case or the current case.} \end{cases}$$
- **Value**, it consists of checking the semantic similarity:
$$\begin{cases} \varphi_{ij}^{Value} = 1 \text{ if } C_1 = C_2. \\ \varphi_{ij}^{Value} = \frac{Sim(C_1, C_2)}{\log_2(H+2)}, H \text{ is the height of the ontology.} \end{cases}$$
- **State**: it consists of the health state of the patient. We distinguish three states: (i) normal, (ii) acute illness, (iii) chronic disease:
$$\begin{cases} \varphi_{ij}^{State} = 1 \text{ if } State(C_1) = State(C_2). \\ \varphi_{ij}^{State} \in [0, 1] \text{ if } State(C_1) \neq State(C_2). \end{cases}$$

The global similarity between two experiences (cases) is calculated according to the following equation:

$$W_s = Sim(pastCase_i, currentCase) = \sum_{j=1}^{n} M_{Sim_{ij}} * w_j$$

- n is the number of descriptors,
- i is the number associated with the past case,
- j is the number associated with the descriptor,
- $M_{Sim_{ij}}$ is the local similarity between the past case and the current case in a descriptor j,
- w_j is the associated weight of the descriptor j, with $0 \le w_j \le 1$ and $\sum_{j=1}^{n} w_j = 1$: it expresses the importance the experience descriptor.

5. Case study

This case study requires interaction between at least two speciality X and Y. The interaction between the different arguments is represented by a graph of attacks [2–4]. In a knowledge base the graph of attacks is defined as *fact*. Therefore, to check the consistency of the knowledge base, the constraints must be applied on the designed graph of attacks.

For the case study, we will reuse the case already treated in [3], wherein we put some constraints (taking into consideration the weighting of arguments and medical deontology concepts) for eliminating some inconsistencies in the designed knowledge base.

The case treated in [3] concerns a demonstration of a 75 years old overweight woman (Body Mass Index (BMI): 35 kg/m^2 with 20 years history of type 2 Diabetes who complaints of visual disorders disclosing diabetic macular oedema, retinal vein occlusion, and small eye's diabetic. Hence, there is a clear necessity of the collaboration between different medical professionals with different specialities for treating this patient.

[2] www.hon.ch.

	Stakeholders	Reasons	Options	Concerns	Goals
1	Attending physician	Not make invasive investigation or treatment (α)	$\searrow$*Proc*	keep the patient alive and preserve patient's life expectancy and quality of life	Reduce risks such as side effects
2	Ophthalmologist	Perform invasive investigation and treatment (β)	$\nearrow$*Proc*	keep the patient alive and preserve patient's life expectancy and quality of life	Cure patient visual disorders
3	Geriatrician	Check up all others complications of diabetes (macro and micro vasculars) and evaluation of cognitive and metabolic disorders (dyslipidemia, obesity, sarcopenia obesity, ...) (γ)	$\nearrow$*Proc*	keep the patient alive and preserve patient's life expectancy and quality of life	Prevent of dysmetabolism and microalbuminuria or others macro or micro-vascular complications
4	Diabetologist	Prescribe treatment (δ)	$\nearrow$*Proc*	keep the patient alive and preserve patient's life expectancy and quality of life	Maintain blood glucose levels in the normal range

Fig. 5. Stakeholders argumentation [3].

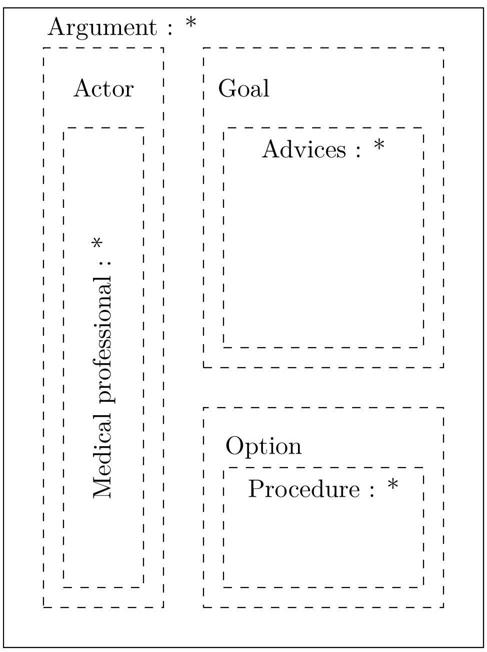


Fig. 6. Internal structure of an argument.

In this case study, the available information is modelled as depicted in the Fig. 5.

The Fig. 5 brings together information on all arguments provided by different medical professionals (Attendant, Ophthalmologist, Geriatrician, Diabetologist) involved in the act of teleexpertise. The graph of attacks is built based on the gathered pieces of advice regarding an algorithm proposed by *Bourguet* in his thesis [15]. The principle of his algorithm is based on the mechanism of projection explained in the previous sections. It is the following: "*if the option of an argument does not project itself in the option of another argument, then it exists an attack relation between them*". The structure of an argument is depicted in Fig. 6, represented as nested nodes (with an internal structure that will be modified on the following sections).

In this work, we are dealing with structured argumentation framework [15,31,32] where nodes or arguments involved in the argumentation system have internal structure and represented in the formalism of nested graphs.

- **Actor**: represents information about the medical professional who is providing the argument :
  - **Medical Professional**: represents the speciality of the concerned medical professional.
- **Goal**: represents the goal that the medical professional wants to reach by giving this argument. To reach it, some advice and sources that support them must be provided:
  - **Advice**: represents the proposal of the medical professional for the treatment of a patient.
- **Option**: represents the option chosen by the medical professional for the treatment of the patient.
  - **Procedure**: Here we consider two options which are declined into procedures : invasive treatment ($\nearrow$ *Proc*), non-invasive treatment ($\searrow$ *Proc*).

After applying the algorithm, the resulted graph of attacks is represented in the Fig. 7.

As said above, the graph of attacks is designed in the knowledge base as a *fact* and the constraints will be used to check if there are inconsistencies in the knowledge base. In this work, we suppose that inconsistencies appear when the laws governing the practice of the teleexpertise are not met. So, in the following, we will recall some laws governing this practice and model them as constraints in the knowledge base for checking its consistency regarding these laws and show how the skills of medical professionals can be weighted and modelled as constraints. First of all, we will see how to define weights over skills (competencies).

5.1. Modelling weights as constraints in CoGui

Taking into account the notion of competence level and sources, one has to modify the internal structure of the arguments to fit the changes. An argument is then represented as depicted in the Fig. 8.

Additionally to the internal structure of an argument (Fig. 6), we added new concepts in order to reach our goal:

- **Level**: represents the level of competency of the medical professional who is supporting this argument. It is an evaluation criterion of medical professionals whose competences is declined into six cores skills [21].
- **Sources**: as its name suggests, this concept represents the sources of information used by medical professionals to justify their decisions (pieces of advice). These sources can be derived from medical books, medical articles, past experiences, information on the Internet, etc.

Practically, the weights are calculated by the Algorithm 1 according to the competencies and the sources. For the weighting of the competencies, it consists of giving static weights since the number of competencies are known and limited. With regard to the weight of the sources, different weighting methods are applied depending on whether the sources are medical information on the Net, medical articles in journal, medical books or past experiences (see Table 1).2lm

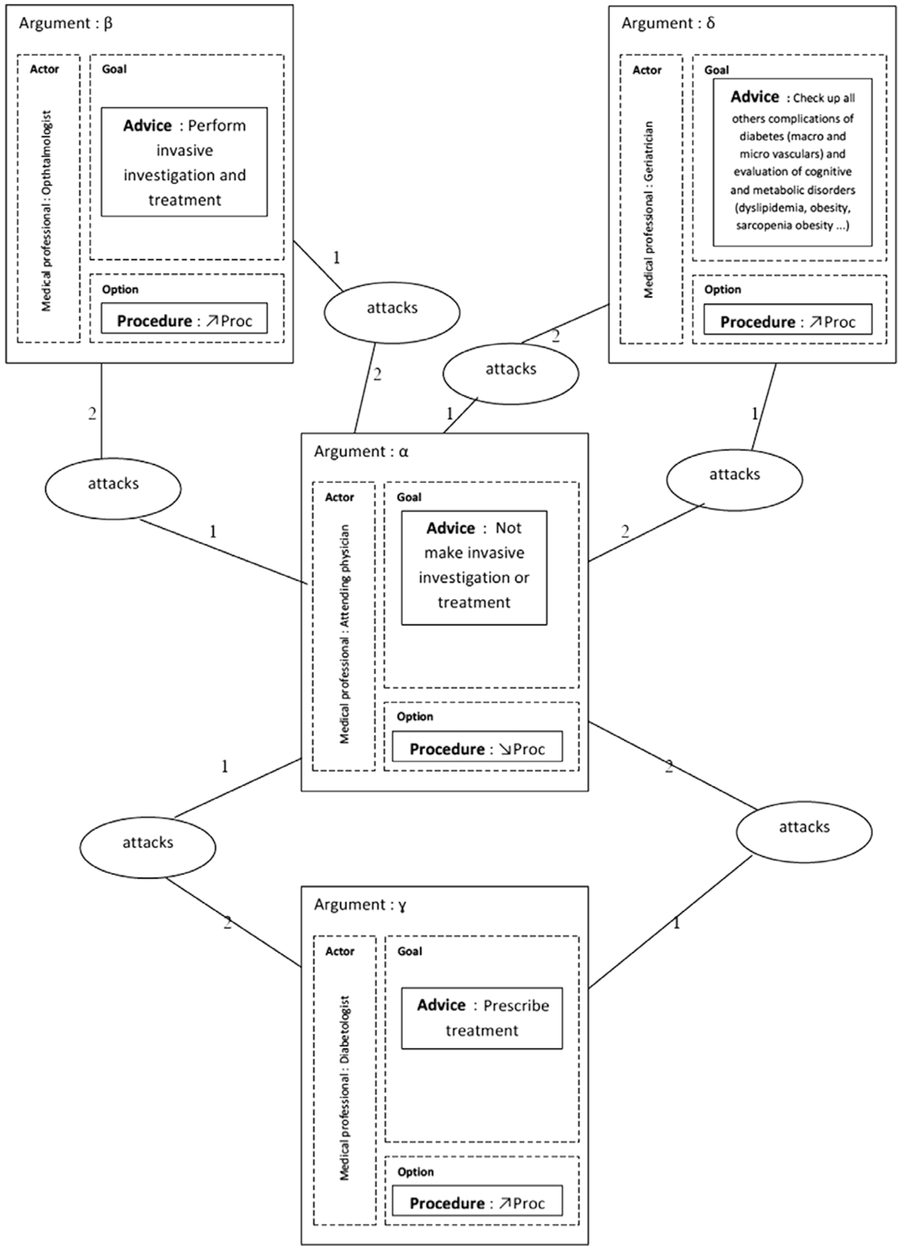


Fig. 7. Graph of attacks in conceptual formalism [3].

Table 1
Weighting of the arguments using Algorithm 1 with $\alpha = 0,2$ and $\beta = 0,8$.

Argument of	Level of competency	$\mathcal{W}_l$	Sources	$\mathcal{W}_s$	Weight of argument (W_A)
Attendant	Advanced beginner	0,4	Medical journal	0,33	0,35
Ophthalmologist	Competent	0,6	Medical journal	0,47	0,5
Geriatrician	Expert	1	Past experience	0,68	0,75
Diabetologist	Novice	0,2	Medical journal	0,95	0,8

After the weighting of all arguments, then the weights will be assigned to the corresponding argument in the knowledge base. For our case study, the resulted weights are:

- The weight of the argument of the Attendant is W_A (Argument alpha) = 0,35
- The weight of the argument of the Ophthalmologist is W_A (Argument beta) = 0,5
- The weight of the argument of the Geriatrician is W_A (Argument delta) = 0,75
- The weight of the argument of the Diabetologist is W_A (Argument gamma) = 0,8.

In CoGui [9], we designed the graph of attacks modelled as fact (ref. Fig. 9) while not taking into consideration the internal structure of arguments.

To check the consistency of the graph of attacks given in Fig. 9, one should confront it with necessary constraints. In the Fig. 10 is depicted a negative constraint.

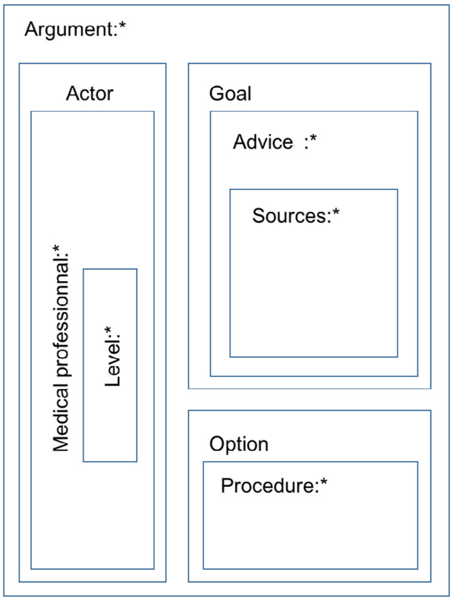


Fig. 8. New internal structure of an argument.

This constraint expresses that: "if the weight of an argument is greater than the weight of another argument, then this later must not attack the first one". In the case study, it means that the argument of a medical professional should not be attacked by another argument with lower weight. This constraint does not prevent an argument to attack another argument whatever its weight. The graph of attacks is built without taking into consideration the weight of arguments and then the constraint is used for identifying the bad attack relation.

The Fig. 11 shows the inconsistencies of the knowledge base. The *attacks relation* in red colour should not exist. It means that there is a bad *attacks relation* between two arguments according to the necessary constraints and this may not be taken into account (must be removed) when computing semantics acceptabilities. The algorithms proposed by [3] can then be used to compute the desired acceptability semantics since the argumentation is modelled with the conceptual graphs formalism.

The compliance with laws is an obligation [33] when performing medical practices and this obligation can be modelled in conceptual graph formalism as constraints. This will be the subject in the next section; in other words, trying to model some laws concepts in medical collaborative activities.

Data: $\mathcal{W}_l$, $\mathcal{W}_s$, α, β
Input: A: an argument
Output: W_A: the weight of the argument A

if $A\,! =$ *null* **then**
  $l =$ getLevel(A);
  $s =$ getSources(A);
  if $l ==$ *Novice* **then**
    $\mathcal{W}_l = 0,2$;
  else if $l ==$ *Advanced Beginner* **then**
    $\mathcal{W}_l = 0,4$;
  else if $l ==$ *Competent* **then**
    $\mathcal{W}_l = 0,6$;
  else if $l ==$ *Proficient* **then**
    $\mathcal{W}_l = 0,8$;
  else
    $\mathcal{W}_l = 1$;
  if $s ==$ *medical information on the Internet* **then**
    $\mathcal{W}_s$ is calculated using NetScoring or Health on the Net;
  else if $s ==$ *medical articles in journals* **then**
    $\mathcal{W}_s = \frac{\text{impact factor}}{\max(\text{Existing impact factor})}$;
  else if $l ==$ *medical books* **then**
    if *known editor* **then**
      $\mathcal{W}_s = 1$;
    else `/* when the medical book is unknown */`
      $\mathcal{W}_s = 0,5$;
  else `/* when the source is a past experience */`
    $\mathcal{W}_s = Sim(pastCase_i, currentCase) = \sum_{j=1}^{n} M_{Sim_{ij}} * w_j$;
  return $W_A = \frac{\alpha\mathcal{W}_l + \beta\mathcal{W}_s}{\alpha+\beta}$;
else
  return 0;
end

Algorithm 1: Weighting an argument

5.2. Modelling laws as constraints in CoGui

In our works, we are interested in teleexpertise which is a practice of telemedicine allowing the collaboration between remote medical professionals with different specialities.

Globally, when practising a medical act, one of the major obligations is the **patient rights**, which consist of informing a patient

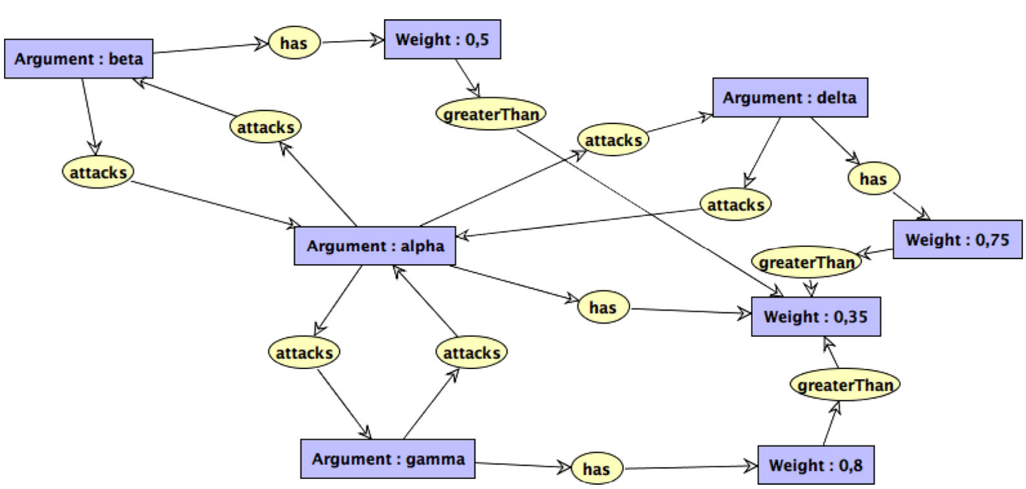


Fig. 9. Graph of attacks with weighted argument.

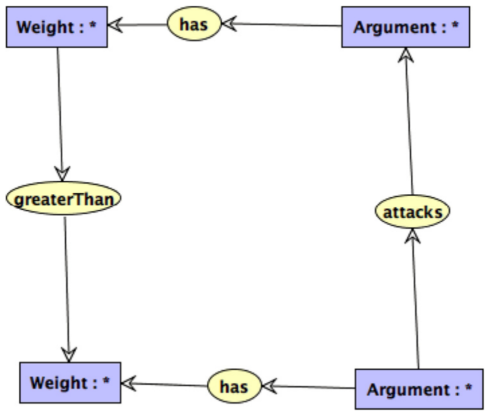


Fig. 10. Weighted argument with negative constraint.

about the concerned medical practice and how and what for his data will be used, then getting his consent or, where requisite, that of his legal representative for using it or not, in accordance with the ethical principles of the Declaration of Helsinki on medical research involving human subjects. However, the patient still having the right to object. The **identification of the actors** (medical professionals, patient) is also an obligation of a medical practice in which the health professional must be authenticated and had the right to access the patient's medical data necessary in the use of a specific medical practice. The concerned patient must also be identified. The last two obligations of a medical practice are [34]: (i) **traceability and prescriptions**, this is represented by a report containing all the prescriptions, the realised practices, the identity of the health professionals, the date, the time and if appropriate, some occurred incidents, (ii) **management of the act of telemedicine** which consists of handling the problems of health insurance.

In this work, we want to check the consistency of the graphs of attacks in the knowledge base by using constraints. The first contribution has been to consider the weight of the arguments to identify the inconsistencies. The second contribution is to express the medical and legal obligations as constraints.

The first constraint is based on the patient consent, in other words, when the patient (or his legal representative) did not give his consent or he refused then the graph of attacks is invalidated which means that no argument attacks another one. This is expressed as negative constraint in the Fig. 12. One can notice that the concept *Patient_Consent* is isolated: this is not a problem since the knowledge formalisation in conceptual graphs supports isolated concepts.

The Fig. 13 shows the verification of the negative constraint depicted in the Fig. 12.

A health professional should have access to necessary data for patients' treatment as said in the obligation of the **identification of the actors**, otherwise an argument given by this latter should not attack any other arguments. This can be expressed as negative constraint depicted in Fig. 14, where the entity PMR represents the Personal Medical Record of the patient in which one can find all the patient's medical data.

For example, we suppose that, among the medical professionals involved in the teleexpertise of the case study, the *Ophthalmologist* has not received necessary data that could help him to make right decisions. According to the constraint (Fig. 14), his provided argument should not attack any argument; the inconsistency is depicted in the Fig. 15 in red colour (attacks relation).

This section has shown that some guidelines of medical deontology representing obligations can be modelled as constraints in conceptual graphs with a logical semantics allowing formal verifications.

These constraints based on the weight of arguments and laws are very important in collaborative medical processes in the sense that they allow the verification of inconsistencies such as bad attacks relation and the compliance of some guidelines of medical deontology.

6. Results and discussions

The ideas proposed in this work are to check if there are inconsistencies in a knowledge base for collaborative processes in medical practices. These lines of reasoning are based on the weighting of the health professionals' advice (arguments in an argumentation system framework) given during a collaboration

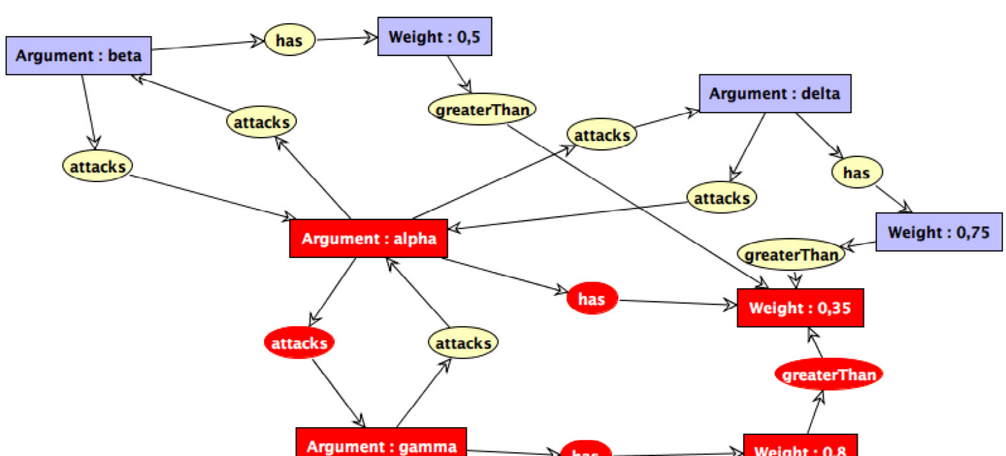


Fig. 11. Weighted argument with inconsistency verification. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

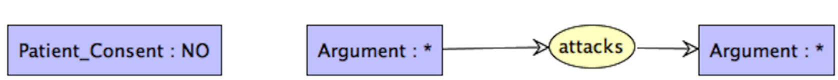


Fig. 12. Negative constraint for patient consent.

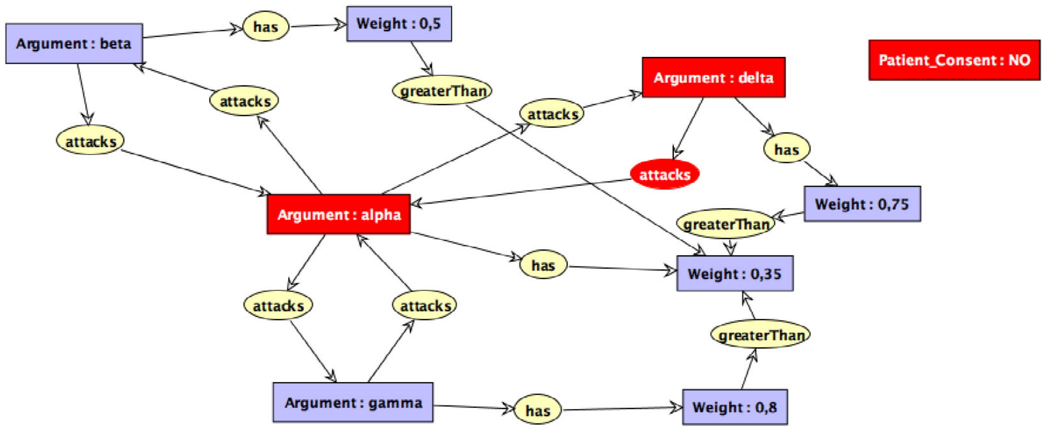


Fig. 13. Patient consent inconsistency verification.

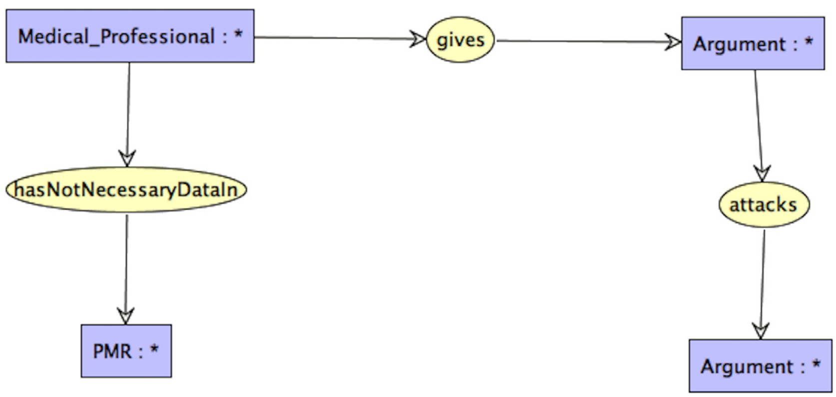


Fig. 14. Data access negative constraint.

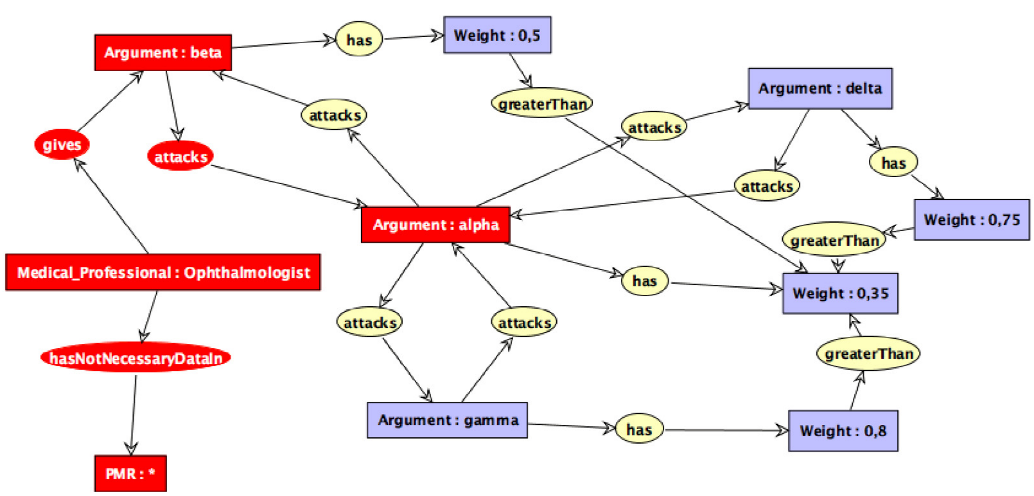


Fig. 15. Data access inconsistency verification. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and the consideration of some guidelines of medical deontology concepts in the modelling. In our previous works, we proposed a methodological framework where the arguments are collected by a server [3], and the graph of attacks is built considering that all these arguments have the same weight [2,3,11], the usage of the weighted arguments and legal concepts will allow the refinement of the graph of attacks and then to compute the right decisions (semantics of acceptability).

The practice of telemedicine is likely to lead to the multiplication of legal risks in behaviour of health professionals. This remote practice can generate cases of professional misconduct for which there is individual criminal responsibility for the contribution to the damage caused or lack of avoidance measures [34]. This is the case of the practice of teleexpertise, when an involved health professional handles unreliable or non-exhaustive medical data. For example, a wrong interpretation made by a radiologist based on a poor quality of an X-ray could lead to create a damage which could have been avoided if the radiologist refuse to undergo a medical interpretation, while taking into account the quality of elements received for the diagnosis. The proposed work could help to avoid this kind of situation.

The proposed method can be generalised to other domains where collaboration for decision-making is needed. The generalisation can be done by a methodology including the main following steps: (i) acquisition of the domain vocabulary by an ontological model, (ii) modelling of the argumentation based on the ontological model, (iii) knowledge representation and reasoning with conceptual graphs having an underlying logical formalism.

At the application level, our research work falls within the framework of decision support systems applied in the medical field, it would be fruitful to be able to describe the information gained from case studies tested in a software application that implements our conceptual contributions. This is interesting for the capitalisation of the lessons learned, which could contribute for the optimisation and improvement of software modules connected of the argumentation system integrated in the computer systems for decision-making in medicine [35].

This software implementation of proposed methodology will be of practical interest for multidisciplinary team (MDT) meetings, which bring together health professionals from different disciplines whose skills are essential to make a decision that gives the patient the best possible care according to the current state of science. In oncology, MDT meeting is required for decision-making on the cases of all patients and takes place in a health facility, a group of health facilities, a network of cancer researchers, or in cancer coordination centres (3C). However, MDT meetings are not exclusive to oncology and can be used in other medical specialities, especially for complex care and geriatrics. In all cases, it is necessary to ensure the traceability of the application of the decisions from the MDT meeting for the diagnosis and for the treatment of the patients (or clearly argued and well-justified doubts for its non-application). In our case studies, a result obtained is the guarantee of the traceability of the reasoning used by the medical professionals during their collaborations while ensuring a semantic interoperability of the system and a resolution of certain ethical problems [36]. To achieve this result, we have combined the system of argumentation with the formalism of conceptual graphs. The traceability of the reasoning process is made possible by the use of an abstract argumentation framework in which the graphs of attacks allow the faithful transcription of interactions between medical professionals. At the same time, the associated procedures for calculating acceptability semantics for decision support systems. As for semantic interoperability, it is made possible by the use of conceptual graphs (linked to languages of semantic web) in the modelling of argumentation systems.

The results obtained also make it possible to resolve the following ethical issues:

- **Transfer of insufficient clinical information**: in our approach, information is sufficient since only the clinical information required for the practice of teleexpertise are sent to the different stakeholders.
- **Little or no communication between the doctor and his patient**: our model ensures good communication between the patient and his doctor. Indeed before any use of the patient's data, the physician must first explain how the data will be used in order to obtain its consent.
- **Imprecise and vague report**: the proposed tool allows to generate a clear report on the basis of the reasoning behind the drafting of the different arguments of the collaborative expertise, because the used knowledge representation formalism can be translated into various natural languages.

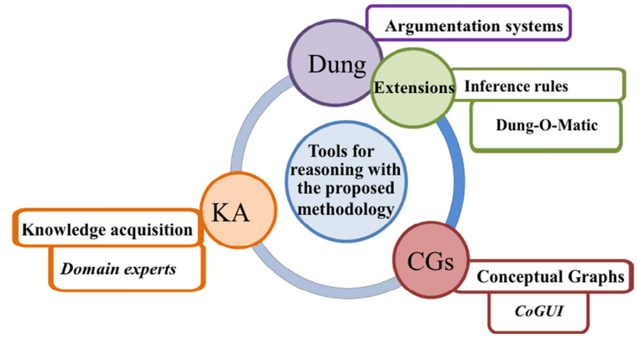


Fig. 16. The tools used to support the architecture.

- **Safety of medical data**: this problem is solved in our proposal, since any access to the medical information collected and transferred requires the consent of the person concerned or of his legal representative.

In order to support the methodological approach and research activities undertaken to complete the comprehensive characterisation of the framework proposed with a modular and expendable design, we rely on the following architecture that presents the used tools (Fig. 16).

The knowledge acquisition is done with a specific module (Algorithm 1) integrating the credibility measurements of sources in order weighted the provided arguments. In our case, we incorporate some external procedures that can support the weighting of the considered evidence. This assessment should be based on a broad range of contextual indicators and constraints while also taking account of the past experiences and the level of expertise in relation to each professional speciality.

As reference support for the argumentation reasoning processes, we rely on the Dung-O-Matic [37] that is an argumentation system based on dialectical proof-procedures and including implementations for a lot of semantics. Searched and required useful extensions for a given Argumentation Framework can be computed. In some cases, the data can be saved and stored during reasoning processes for later use during information retrieval and knowledge capitalisation. Implemented as a Java library, it can be flexibly used across platforms. It is available via the tool OVAgen[3] that is a web-based software where argumentation frameworks can be displayed graphically and the subsequent extensions are visualised.

In view of ontology modelling, we selected Conceptual Graphical User Interface (CoGui) [38] because of the flexibility of this toolbox, the modularity of the reasoning components and the user interface that allows efficient knowledge structuration and management with graph-based operations. The intuitive user interface of CoGui provides the ability to customise any ontological favourites and diverse models of conceptual graphs with a selection of advanced guidance and reasoning tools for inheritance or instantiation and constraints checking. CoGui supports the import and export functions of some formats used by the languages (e.g. Resource Description Framework (RDF) and Web Ontology Language (OWL)) used in the semantic web and this facilitates the interoperability management at a conceptual level (syntactic and semantic aspects).

[3] http://ova.arg-tech.org/ova-gen/.

7. Conclusion

This work has permitted us to propose innovative solutions in order to check inconsistencies that could occur in collaborative medical processes and overcome them whenever it is possible. The major contributions are the weighting of the health professionals' advice (ref. Algorithm 1) and the consideration of some guidelines of medical deontology in collaborative processes; the whole modelled as constraints in conceptual graph formalism coupling with argumentation system [5] for inconsistency detection.

We think that this work will bring new contributions in the domain of medical expert systems [39–41] for collaborative medical practices in order to make and take right decisions while taking in consideration medical–legal concepts such as patient consent and medical data access. In case of legal procedure, this could help to easily identify the responsibility incurred by each stakeholder since it is very difficult for the judge to decrypt it [34].

In this work, the weighting of the pieces of advice takes into account both the level of competency of a health professional and the sources of his justification information. The proposed work is illustrated using a concrete driving example that could guide the reader in understanding the whole system. In essence, this example is partially executed in the Conceptual Graph User Interface (GoCui), but it constitutes a milestone is the completion of one stage of the considered research. In the practical perspectives, developing the prototype will be even more demanding and will involve much more of an insight into the needs of the medical professionals in question. Indeed, it is based on a theoretical framework called Dung Argumentation Framework. The usage of such framework allows for representing the interaction between the different stakeholders during collaborative activities for the decision-making process. The modelling tool called CoGui is used to illustrate our proposal since it includes constraints modelling, allows the representation of the interaction and the visualisation of the reasoning process.

In perspectives, we would like to propose some solutions on how to develop tools for the weighting of the health professionals' advice (arguments) during collaborative medical practices such as teleexpertise.

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