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Argumentation Systems for History-Based Construction of Medical Guidelines

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Abstract

Medical guidelines are hard to formalise because of their inherent fragmentary nature. Because of this, a formalism where details of guideline text are omitted is justified. In this paper, we describe medical histories and expectations and illustrate them with a number of examples from the Dutch breast cancer guideline. We applied our approach to an assumption-based argumentation system for its reasoning facilities to support guideline construction. Examples concerning treatment selection in the breast cancer guideline are discussed.

1 Introduction

Medical guidelines consist of advices about proper actions, concerning therapy, diagnostic tests, and preventive measures. The aim is to guarantee achieving optimal care results by advising to select actions that are considered best, at the same time attempting to minimise risks and avoiding side effects of these actions. Nowadays, medical guidelines are evidence-based, in the sense that guideline developers make conscientious, explicit, and judicious use of current best practice evidence in constructing these advices about the care of individual patients [8]. However, as also pointed out by Sackett et al. [8], evidence-based medicine is not ‘cookbook’ medicine. It requires a bottom up approach that integrates the best external evidence with individual clinical expertise and patients’ choice, which is incompatible with a slavish, cookbook approaches to individual patient care. Instead, evidence-based guidelines attempt to give advices for particular clinical situations that are reasonably common when there is not a general consensus to actions which should be taken. The selection of these situations identifies the scope of the guideline, after which the problems are broken down into a series of structured key questions which are used to find relevant evidence.

As a result, modern evidence-based medical guidelines are fragmentary in nature, which renders it hard to formalise them. Filling in the gaps is a time-

consuming task which could require excessive amounts of domain knowledge; the result would be far beyond the scope of the original guideline. In this article, we argue that a fragmentary approach for representing a guideline is feasible. A consequence of adopting such an approach is that we need to abstract from the details of a guideline text, but for checking the quality of a guideline it is not always possible to omit detail. The representation we present in this paper allows for a sufficiently high level abstraction, in such way that essential elements of the guidelines are highlighted. As the ultimate aim is to support the development of medical guidelines and to study their properties, the theory is necessarily formal in nature.

Logic is an obvious choice to formalise knowledge about guidelines. However, as the type of information that a guideline captures is extremely diverse, a modular approach to formalisation is needed. In addition, much of the reasoning about this knowledge is non-monotonic, which provides an even bigger challenge. Previously, we have addressed this issue by considering treatment selection as a special form of abductive reasoning [4]. In this paper, we will present a part of a formalisation for fragmentary parts of a guideline with some basic deductive facilities, which is work that has been built upon our previous work described in Ref. [5]. In addition, its reasoning system is extended with an argumentation system facilities, which have gained a lot of attention in the last decade by research in formal logic and philosophy, as it attempts to formalise practical human reasoning. There have been numerous applications in legal reasoning (e.g., [6]), but also in the context of medical guidelines they are being used [3]. The application of argumentation systems support our claim that, even though we make large abstraction of the guideline text, it is sufficiently concrete to reason about the knowledge that is of importance for the construction of a guideline.

In Section 2 we will present a framework for formalising knowledge which lies at the basis of guidelines, consisting of histories and expectations. Subsequently, in Section 3 we will show how an argumentation system with histories and expectations as its underlying deductive system can be used and we will provide some examples of this. Finally, in Section 4 some final conclusions, a short comparison to the *PROforma* system is made, and hints for future work are mentioned.

2 Framework for Formalisation of Guidelines

In this section we discuss a number of essential elements that can be found in medical guideline text.

2.1 Basic Elements

The examples we present here were extracted from a medical guideline regarding breast cancer by CBO [2], an institute that has supported the development of most of the guidelines developed so far by the Dutch medical specialists.

Example 1. *Since the treatment of choice is usually neoadjuvant chemotherapy, and since it may not be possible to collect live tumour tissue after chemotherapy,*

it is advisable to establish a histological diagnosis by means of a core biopsy.

The goal of this text is to provide a rationale to perform a core biopsy before chemotherapy. At the same time it consists of a piece of domain-specific information that might be used to detect flaws that may occur in other parts of the guideline. The structure of such information is quite common in medical guidelines in the sense that descriptions of medical knowledge typically combine information about time or orderings over time, about the patient and its environment and finally what intervention or set of interventions is administered to the patient. In this case, it consists of two interventions ‘neoadjuvant chemotherapy’ and ‘core biopsy’, a partial description of the patient namely the ‘possibility to collect live tumour tissue’ and finally a constraint on the time: ‘after’.

We will discuss these three elements in more depth and propose an initial formalisation.

Time Time is used in a guideline to model the changes in situation of the patient and its environment. Research has shown that an imprecise time axis is sufficient in most cases. However, sometimes guidelines are more specific and actually give reasonably precise time frames, but only in a limited number of cases medical science is as precise as physics. Hence, a formalisation of time should allow for an extension of the cause-consequence relationship. Consequently, we assume there is a set **Time** and a relation $\preceq: \text{Time} \times \text{Time}$ such that \preceq is reflexive and transitive, i.e., \preceq is a pre-order. Note that \preceq is not anti-symmetric in general, because there can very well be different descriptions of the same points in time. Moreover, we do not assume that this ordering is known, but in general there are known constraints with respect to this order.

State A state can provide a description of the actual situation of a patient given all known facts and more general situations of individual patients. The traditional technique to abstract from a certain situation (a model) is by providing a logical language that refers to one or more situations without fixing all the details. Typical elements in the state of a patient are symptoms, signs and other *measurable* elements. Because many of these elements are unknown and often irrelevant we have chosen to define the state space as a many-sorted first order logic **State** including equality, but excluding any free variables. Let there be a structure \mathcal{A} consisting of a domain for every sort σ and an interpretation I of every constant of a given sort to the domain of this sort such that $I(c_i^\sigma) \neq I(c_j^{\sigma'})$ where $i \neq j$ or $\sigma \neq \sigma'$, i.e., we assume unique names. Let **State** be a language built up inductively consisting of terms and propositional connectives in the traditional manner such that elements of **State** can be interpreted on the structure. For example, typically $\text{temperature} = 37 \vee \text{systolic-blood-pressure} = 120$ is an element of **State**. Note that in the upcoming sections we will leave the different sorts implicit.

Intervention Interventions include medical actions that influence the condition or the environment of a patient. The domain of interventions is formalised as a countable set **Interventions**. The interpretation of a subset of the **Interventions** is a treatment where each intervention is applied, either in sequence or in parallel.

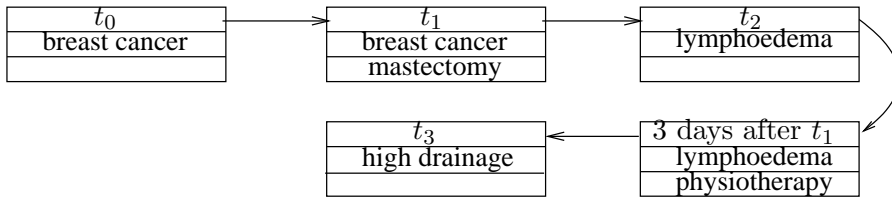


Figure 1: Formalisation of Example 2. The arrows define a strict ordering between the time points.

Furthermore, we have a closed-world assumption for each set of interventions I which says that if $i \notin I$, then intervention i is not applied.

2.2 Histories

Let $\wp(X)$ denote the powerset of X and let $[V \rightarrow W]$ denote the function space of functions $f : V \rightarrow (W \cup \{\epsilon\})$, where ϵ will have the interpretation ‘undefined’. Let a time constraint be of the form $t \preceq t'$ or $t \not\preceq t'$. A model of a set of constraints is a total pre-order. In this paper, assume that $t_i \prec t_j$ iff $i < j$.

A medical guideline contains descriptions of processes concerning the disease, medical management and recommendations. Static descriptions of the different aspects of patient groups as we have described above are captured in a history as defined below.

Definition 1. *A history is defined as an element of the set $History$ such that $History = [Time \rightarrow (State \times \wp(Intervention))]$ in combination with a set of time constraints \mathcal{C} .*

Example 2. *After a mastectomy or breast-conserving treatment, there is an increased risk of movement problems, impaired sensation, pain, and lymphoedema. Adjuvant radiotherapy increases the risk of limited movement of the shoulder and of lymphoedema. Physiotherapeutic intervention can have a positive effect on the recovery of mobility and functionality of the shoulder joint. Early initiation of intensive remedial therapy (in other words, during the first postoperative week) has an unfavourable effect on the wound drainage volume and duration.*

There are several possible ways to formalize this excerpt depending on the focus of the modeller. One possibility is to pick some patient-group, for example the patient-group which receives physiotherapy too early after the mastectomy. See Figure 1 for a graphical representation of such a history. Note that these elements of $Time$ do not express anything about the *distance* between the time points. So the distance between t_0 and t_1 is not necessarily the same distance as the distance between t_1 and t_2 . In addition to being imprecise about certain patients it also allows us to ‘instantiate’ patients of a certain patient-group by adding patient-specific information to this history.

We will call two histories h and h' inconsistent if there exists a $t \in \text{Time}$ such that $(s, I) = h(t)$ and $(s', I') = h'(t)$ where the conjunction of s and s' is inconsistent. Otherwise, h and h' are consistent.

2.3 Expectations

When dealing with guidelines, we are concerned with the dynamic aspect, for example, the description of how a history is *expected* to continue and what we can conclude about what happened to the patient in the past. As a consequence, this means that the history is extended with new information. A typical example is an expectation of a treatment, i.e., the expected history that a certain treatment yields. First we introduce some notation.

Definition 2. *Given a history h and h' then h' is an extension of h iff (1) $\text{dom}(h) \subseteq \text{dom}(h')$ and (2) for all $t \in \text{Time}$: $h(t) \neq \epsilon$ and $(s, I) = h(t)$, then there exists (s', I') such that $h'(t) = (s', I')$ and $s' \rightarrow s$ and $I = I'$.*

Definition 3. *The projection of a history h to two elements $i, j \in \text{Time}$, denoted as $\langle h \rangle_{(i,j)}$, is defined as the history h' such that: (1) $\text{dom}(h') \subseteq \text{dom}(h)$, (2) for all $t \in \text{Time}$: $h(t) \neq \epsilon$ implies $h(t) = h'(t)$, and (3) $t \in \text{dom}(h') \Rightarrow i \preceq t \preceq j$.*

Obviously, a history is always an extension of a projection on itself. With these definitions, an expectation function is defined.

Definition 4. *The expectation of a given history is the function space: $E = [\text{History} \rightarrow \wp(\text{History})]$ such that for each $e \in E, h \in \text{History}$ holds: (1) $h' \in e(h) \Rightarrow h'$ is an extension of h and (2) let $m \in \min(\text{dom}(h)), M \in \max(\text{dom}(h)), i \geq M$: $e(h) \supseteq \bigcup_{h' \in e(h)} e(\langle h' \rangle_{m,i})$.*

The first condition expresses that expectation functions only *extend* histories, i.e., no information is lost. The second condition makes sure that an expectation function is consistent with itself. Intuitively, it says the expectation does not contradict expectations of expected histories.

The expectation function of a treatment is defined as the function e_I such that for all h , $e_I(h)$ is $e(h')$, where for h' it holds that for all maximal t in the domain of h , the set of interventions in $h'(t)$ is the union of interventions of $h(t)$ and I and for all other t , it holds that $h(t) = h'(t)$.

3 Application to Argumentation Systems

It is often the case that there is not a conclusive argument for or against a treatment for a certain patient group. This is particular the case during the design of medical guidelines when recommendations for rather large groups of patients are constructed. It is well known that in medical reasoning and in particular diagnosis, abductive reasoning is often used. This amounts to constructing a hypothesis about the patient after which this hypothesis is checked against the observations that have been made. If they are consistent with observations, then the hypothesis is accepted and otherwise they are rejected. In our previous work, we used such

abductive reasoning to find treatments which are consistent with the intentions that one wants to reach [4]. A similar type of reasoning in the context of defeasible reasoning can be found in so-called *assumption-based* argumentation systems [1]. The definitions below are based on histories and expectations, where patients and patient groups are represented as histories. In this framework arguments are not completely abstract, but they consist of a number of assumptions together with a conclusion. The defeat relation between these arguments can then be used to find the status of individual arguments. Arguments can be *justified* or *overruled* and moreover *defensible* if they can not be assigned a justified or overruled status. For background on argumentation systems, we refer to [7]. Arguments and the defeat relation between them are defined as follows.

Definition 5. Let $Args(p, I)$ be a collection of arguments in a dispute about patient p concerning the set of interventions I . Arguments are denoted as $As \Rightarrow Co$ where the assumptions As is a specific patient group of p , i.e., As is an extension (see Definition 2) of p . Furthermore, the conclusion Co is a patient group such that there exists a $As' \in e_I(As)$ and As' is an extension of Co' .

Definition 6. Argument A defeats B if (1) the conclusion of A is inconsistent with the assumptions of B (A undercuts B) or (2) the conclusion of A is inconsistent with the conclusion of B (A rebuts B) and B does not undercut A .

Example 3. Suppose we would like to find out whether or not a patient has breast cancer. A core biopsy can be used to diagnose this patient, however, if the patient received chemotherapy in the past, then the core biopsy will not result in a diagnosis.

Let p be a patient of which there does not exist any information on a certain time point t_1 , i.e., $p = \{(t_1, \top, \emptyset)\}$ and let the intervention be a core biopsy. We can construct a simple dispute, with an argument as follows:

$$\{(t_0, \top, \{\text{chemo therapy}\}), (t_1, \top, \emptyset)\} \Rightarrow \{(t_0, \top, \{\text{chemo therapy}\}), (t_1, \top, \{\text{core biopsy}\}), (t_2, \neg\text{diagnosis}, \emptyset)\}$$

However, assuming that it is not expected that anyone has had chemo therapy, this argument is defeated by $\{(t_1, \top, \emptyset)\} \Rightarrow \{(t_0, \top, \emptyset), (t_1, \top, \{\text{core biopsy}\})\}$. It is easy to see that this argument cannot be undercut or rebutted by a consistent argument, because this argument does not assume anything about p to reach its conclusion. Inconsistent arguments, i.e., arguments with an inconsistent state for some time point in its assumption, do rebut and undercut all arguments, but these arguments are undercut by any other argument. As a consequence, inconsistent arguments do not affect the status of the other arguments.

Example 4. Given a patient with breast cancer where the tumour size is large, that is to say, the patient p is described by $\{(t_0, \text{large tumour}, \emptyset)\}$. One possible treatment for breast cancer is chemo therapy to reduce the size, but as this causes a lot of suffering for the patient, it is clear that it should only be recommended if it is helpful for the patient. If the tumour has metastasised, then in general the treatment becomes palliative which often does not include chemotherapy. Let

there be a dispute for this patient group about the use of chemo therapy with the following arguments based on the information mentioned above:

- A. $\{(t_0, \text{large tumour} \wedge \text{metastasised}, \emptyset)\} \Rightarrow \{(t_0, \text{large tumour} \wedge \text{metastasised}, \{\text{chemo therapy}\}), (t_1, \text{died}, \emptyset)\}$
- B. $\{(t_0, \text{large tumour} \wedge \text{local}, \emptyset)\} \Rightarrow \{(t_0, \text{large tumour} \wedge \text{local}, \{\text{chemo therapy}\}), (t_1, \neg\text{died}, \emptyset)\}$
- C. $\{(t_0, \text{large tumour} \wedge \text{metastasised}, \emptyset)\} \Rightarrow \{(t_0, \text{large tumour} \wedge \text{metastasised} \wedge \neg\text{local}, \{\text{chemo therapy}\})\}$
- D. $\{(t_0, \text{large tumour} \wedge \text{local}, \emptyset)\} \Rightarrow \{(t_0, \text{large tumour} \wedge \text{local} \wedge \neg\text{metastasised}, \{\text{chemo therapy}\})\}$

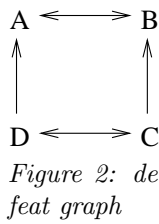


Figure 2: defeat graph

Applying Definition 6 results in the defeat diagram in Figure 2, where the defeat relation is represented by arrows. Argument A and B rebut each other and the other defeat relations are due to undercutting. None of the arguments is undefeated, which means that none of them are in the grounded extension (see [7]). But, there are two preferred extensions $\{A, D\}$ and $\{B, C\}$, so all arguments are defensible, which is what one would expect in this case.

By definition, the conclusions of these are consistent with each other and describe the same patient group. This shows that by doing additional tests, e.g., finding out if the tumour has metastasised, some arguments become invalid after which the other arguments become justified. Such information can be used during the development of a guideline.

4 Discussion

In this paper, we have illustrated that the use of argumentation plays an important role for reasoning about medical guidelines. We have motivated this by a number of examples from the breast cancer guideline. The idea is that argumentation can help to identify which treatments can judiciously be accepted given the knowledge about patient groups, which is crucial during the development of a guideline.

One of the components of the PROforma decision system, described in Peleg et al.[3] is an argumentation system. In this system an argument consists of (1) the claim that the argument deals with, (2) the grounds that justify the argument (as drawn from the knowledge base), and (3) a sign or qualifier that represents the confidence warranted by the argument in the claim. For example, the claim could be that the patient has a gastric ulcer on the grounds that the patient has lost weight and this is consistent with the presence of an ulcer. Hence, in this case the sign is that the grounds *support* the claim. In its simplest form, a total confidence of a certain claim is aggregated as follows: $netsupport(Claim) = \frac{Pros-Cons}{Pros+Cons}$ where pros is the number of arguments that support the claim and cons is the number of arguments against it and by using the qualifier it is possible to give certain arguments more weight than others. In other words, the result of the dispute is only dependent on the conclusion or claim of the argument, i.e., arguments with the same claim and different sign rebut each other. This is the main difference with the

idea presented in this paper, where it is possible to not only rebut other arguments, but also to undercut arguments, which results in more complex reasoning.

Of course, much work has to be done. Firstly, one can say that histories are low-level structures to describe patient-groups. More high-level methods are being developed that allow the characterization of a history. One possibility is to embed the idea of a history inside a logical language. Another possibility is to define certain patterns in histories, e.g., a history with a monotonically increasing parameter. Secondly, as we have argued in [4], the treatment that has to be selected does not only depend on the expected outcome, but also on certain optimality criteria, i.e., one treatment can be better than another treatment given some optimality criterion, for example subset minimality, even if they both cure the patient.

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