The SDA* Model: A Set Theory Approach

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Abstract

Procedural knowledge in medicine is embedded in Clinical Practice Guidelines whose textual condition makes it difficult to share and to reuse. Several languages for formal definition of clinical practice guidelines have been proposed to overcome these difficulties. In order to deal with the huge amount of medical situations, these languages use to be extensive and complex in such a way that they, and the knowledge they are used to represent, are arduous to understand and to manage by non-trained general practitioners. The SDA model is introduced as an alternative language that promotes representation capability and simplicity in such a way that not only computers, but also health care professionals are able to understand and manage easily without any sort of training. Here, a description of this model from a set theory perspective is provided.*

1. Introduction

Clinical Practice Guidelines (CPGs) are systematically developed statements to assist practitioner and patient decisions about appropriate health care for specific clinical circumstances [1]. The main justification of publishing CPGs is to help reducing medical errors and unjustified variations in medical practice, and also to support evidence-based medicine [2]. Unfortunately, CPGs tend to be published in a textual format that reduces their possibilities of making them known and applicable. The idea of using a formal representation to describe and exploit CPGs gave rise to the idea of Computer-Interpretable Guidelines (CIGs) [2] as the way to make computers a means to make CPGs actionable. This idea has been the departing point of multiple and successful languages to formally represent CPGs as CIGs (e.g. Asbru, ProFORMA, EON or GLIF3). In [8] some of these languages are compared to conclude that *data collection*, *decision*, *state*, and *intervention* (or *action*) constitute the basic types of primitives in any CIG's logic flow. Besides this, other interesting constructs of a language to represent CIGs are *sequences*, *concurrences*, *alternatives*, and *loops*.

One of the features of all these languages is that they have been designed to cover the great variety of health care situations that may appear in CPGs and with execution purposes. Therefore, they tend to be far away from the medical doctors comprehension, who have to be trained in order to be able to understand and use them. Here, the SDA* Model is introduced as an alternative language that promotes *representation capability* (i.e. procedural knowledge in medicine can be represented with this language) and *simplicity* (i.e. the understanding and management of the language does not need hard training) in such a way that not only computers but also health care professionals are able to work with it.

The SDA* model is based on the concept of *flowchart* [6] but it is extended with several elements to ease health care procedural knowledge representation, as for example, the concept of state as starting point that allows the execution of the chart from different points, or the introduction of time constraints to introduce time restrictions in medical procedures.

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In section 2 the concepts *term*, *state*, *decision*, and *action* and the way they are represented in the SDA*Model are introduced. Section 3 describes how procedural knowledge represented with the SDA* model can be used by computers. Section 4 introduces the use of the model in the European project K4CARE.

2. The SDA* model

The SDA* model is introduced as an alternative to other formal languages used to represent procedural knowledge in medicine [8] that stresses the concept of simplicity without the lost of description capability of the other ones. The model is founded on the concept of *term* or vocabulary item in the medical domain where procedural knowledge is being generated. Terms are employed to construct the *elements* that once interconnected will describe the medical procedure. The model incorporates non-determinism as a way of dealing with medical situations where the condition of the patient determines that alternative therapies are possible, and a time dimension that allows the SDA* model to represent time restrictions on health care procedures. Although it is not part of the SDA* model, uncertainty and imprecision in medical procedures can be captured at the term level using, for example, fuzzy logic [5]. This will affect the model at both the representational and the execution levels.

2.1. The Universe of discourse

The *universe of discourse* of the SDA* model makes reference to the entire set of terms used in the area of interest in which the model is being applied. These terms can be state, decision, or action terms. *State terms* define the vocabulary that is used to describe the feasible patient conditions or situations in the area of interest (e.g. terms as `high-blood-pressure` to establish a differential treatment or `insured-patient` to define the coverage of the patient). *Decision terms* are the terminology that health care professionals use to condition the sort of treatment to be followed (e.g. terms as `female` or `antecedents-of-heart-problems` that derive the course of professional activities in one or another direction). *Action terms* are the way that medical, surgical, clinical or management actions are identified (e.g. terms as `take-beta-blocker`, `avoid-salt-in-meals`, `make-blood-analysis`, or `visit-endocrinologist` are respective examples of prescription, counseling, ordering a test, or consulting a specialist, which are types of medical actions that may appear in the description of a treatment).

Action terms have related a set of *petitioners* and a set of *performers* in order to permit the description of collaborative medical treatments in which several professionals may interact. Any petitioner in the set of petitioners is allowed to requests the action to be executed (e.g. only medical doctors are allowed to prescribe drugs). Performers in the set of performers are the persons allowed to execute the action (e.g. injecting some drugs can be restricted to nurses and to medical doctors). When any of these sets is empty it means that the action has to be performed, but there is not an indication on which petitioner (or performer) is requesting (or performing) that action.

2.2. The SDA* elements

The terms in the universe of discourse are the basic components of the elements of the SDA* model. In [8] it is concluded that states, decisions, and actions are necessary components of any guideline representation model. Simultaneously, health care treatments are usually structured as a sequence of three professional tasks: assessment, plan definition, and plan performance. All these ideas meet the SDA* model that conceives any representation of a medical treatment as a combination of three types of

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elements: *states*, *decisions*, and *actions*. *States* represent patient conditions, situations, or statuses that deserve a particular course of action which is totally or partially different from the actions followed when the patient is in other state. *Decisions* allow the integration of the variability a treatment has depending on the available information about the patient. *Actions* constitute the proper health care activity in the treatment. For example, the knowledge embedded in the sentence "*medication is likely to be needed where there is any sustained depressive disorder and when the non-pharmacological strategies are not achieving their goals*" [9] is only applicable in the context of the state defined by patients with a `depressive-disorder` who are following a `non-pharmacological-strategy`. In this setting, the decision is whether the non-pharmacological treatment is `achieving-the-expected-results` or not, and the action followed in the first case is to `provide-medication` (the sentence does not specify the action in the alternative case).

As far as the SDA* model is concerned, a *state* is formally defined as a subset of state terms in the universe of discourse. This means that a patient is in a particular state if and only if the patient meets all the terms in the state. A *decision* is a finite sequence of subsets containing decision terms. Each element of the sequence (i.e. set of decision terms) defines an alternative outgoing branch of the decision, aiming at treatments that are restricted to the patients that satisfy that branch. Decision branches can only be followed by the patients whose condition meets all the decision terms of the branch. An *otherwise* branch is a particular sort of decision branch that is followed only if the rest of the branches of the decision are not applicable. Finally, an *action* is a non empty subset of state terms describing a block of health care actions.

2.3. Knowledge representation

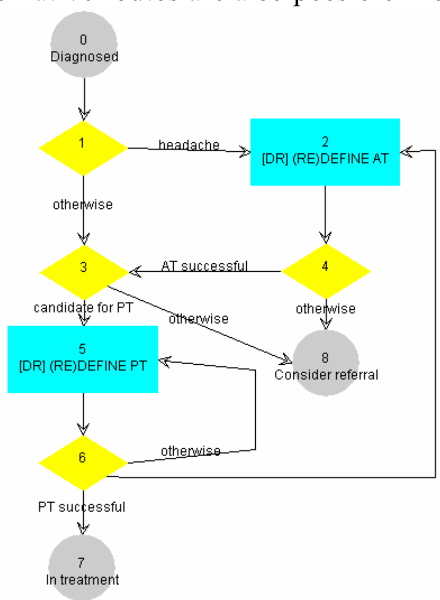
The three elements of the SDA* model (i.e. states, decisions, and actions) are combined to represent procedural knowledge in medicine. This sort of knowledge can describe a diagnostic process (e.g. find out the patient disease or disease stage), a therapy (e.g. what are the steps to follow in the treatment of a disease), or any other health care procedure. The final combination of these elements can be represented in a graphical form as a chart or in a textual form as an XML file.

2.3.1. Flow chart notation: The flow chart notation of the SDA* model represents states as circles, decisions as rhombs, and actions as squares, containing state terms, decision branches, and action terms, respectively. Figure 1(a) shows a SDA* chart on the treatment of *tension-type headache* [3] in terms of:

- The state terms `Diagnosed` (the patient is already diagnosed of this disease), `In-treatment` (the patient is currently following a treatment), and `Consider-Referral` (the patient is visiting a specialist).
- The condition terms `headache` (the patient has headache), `AT-successful` (the acute treatment with *acetaminophen*, *aspirin*, *NSAIDs*, *Midrin*, and/or *adjunctive therapy* is getting good results), `candidate-for-PT` (the patient is candidate for prophylactic treatment), and `PT-successful` (PT is getting good results).
- The action terms `(RE)DEFINE-AT` (the physician `[DR]` provides a combination of drugs for acute treatment), and `(RE)DEFINE-PT` (`[DR]` provides PT).

The chart shows that a tension-type headache patient can be in three states: state 0 (the patient has already been diagnosed), state 7 (the patient is not only diagnosed but also following a treatment), and state 8 (the patient is being treated by a specialist).

The procedural knowledge in figure 1 indicates that if a patient is diagnosed of tension-type headache and he has `headache` (condition 1), then a medical doctor `[DR]` must propose acute treatment (AT) which, if it is successful (condition 4), it must be extend with prophylactic treatment (PT) if the patient is a good candidate (condition 3). Alternative routes are also possible if either AT or PT are not successful.



(a)

```
<?xml version="1.0" ?>
<sda:chart>
  <sda:state id="0">
    <sda:term name="Diagnosed"></sda:term>
    <next> <element> 1 </element></next>
  </sda:state>
  <sda:decision id="1">
    <sda:branch>
      <sda:term name="headache"></sda:term>
      <next> <element> 2 </element></next>
    </sda:branch>
    <sda:branch type="otherwise">
      <next> <element> 3 </element></next>
    </sda:branch>
  </sda:decision>
  <sda:action id="2">
    <sda:term performer="[DR]"> (RE)DEFINE AT </sda:term>
    <next> <element> 4 </element></next>
  </sda:action>
  <sda:decision id="3">
    <sda:branch>
      <sda:term name="candidate for PT"></sda:term>
      <next> <element> 5 </element></next>
    </sda:branch>
    <sda:branch type="otherwise">
      <next> <element> 8 </element></next>
    </sda:branch>
  </sda:decision>
  <sda:decision id="4">
    <sda:branch>
      <sda:term name="AT successful"></sda:term>
      <next> <element> 3 </element></next>
    </sda:branch>
    <sda:branch type="otherwise">
      <next> <element> 8 </element></next>
    </sda:branch>
  </sda:decision> ...
```

(b)

Figure 1. SDA* chart and XML with a treatment of tension-type headache.

2.3.2. Textual notation: An XML Schema has been defined in order to provide a way to share, in a standard notation, the procedural knowledge developed under the SDA* model. Figure 1(b) shows part of the XML representation of the treatment *tension-type headache* depicted in figure 1(a).

2.4. Sequences, concurrences, and loops

The SDA* model allows the description of sequences, concurrences, and loops of medical procedures [2] in an intuitive way, by means of the element connectors. Element connectors are represented as arrows in the chart format, and as `<next>` tags in the XML format. So, if an element A is connected to B (i.e. A→B), this represents a sequence in which A precedes B, and a sequence of connections A→B→…→A represents a loop. For example in figure 1, the elements 0, 1, 3, and 8 describe a sequence, and the elements 2, 4, 3, 5, 6, and 2 a feasible loop.

A *concurrence* is described as a set of actions that should be executed in parallel. In the SDA* model, there are two alternative ways to represent concurrences: on the one hand, when several actions are part of the same action element, this means that all of them are performed simultaneously in time. On the other hand, the introduction of non-determinism permits a kind of loose concurrence in which an undefined number of the concurrent actions may be performed in parallel.

2.5. Non-determinism

Determinism is the principle by which every event, act, and decision (called *effect*) is the consequence of some antecedents (called *cause*). In health care, causes can be

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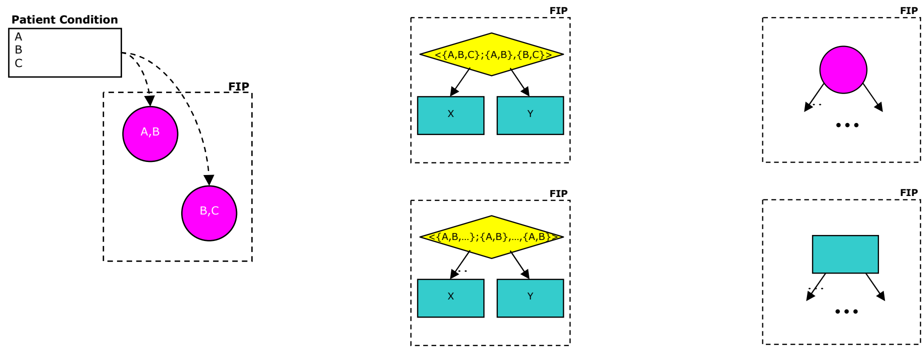
medical, surgical, genetic, environmental, managerial, familiar, social, etc. Therefore, non-determinism states that in health care there are events which do not correspond to a cause. Historically, there have been defined three interpretations of non-determinisms [4]: one that holds that some events are uncaused (e.g. the cause of high temperature is not clear), another one that holds that there are non-deterministically caused events (e.g. alternative equivalent therapies all of them possible), and the third one that holds that there are agent-caused events (e.g. external events as the arrival of a patient whose health condition allows the treatment to start at different points).



(a) (b) (c)

Figure 2. Non-Determinism in the SDA* model.

Independently of the semantics of non-determinism, the SDA* model incorporates it in the ways that figure 2 depicts. Figure 2(a) describes the situation in which a patient with a particular condition (i.e. A, B, and C) matches several states. This means that the treatment of the patient can non-deterministically start at different points. In figure 2(b), the condition of a patient can satisfy several branches of the same decision, and therefore the treatment can follow alternative paths at the same point of decision. In figure 2(c) either a state or an action is connected to several elements causing the treatment to follow one of several alternative evolutions.

2.6. The Time dimension

The SDA* model establishes two sorts of temporal constraints: those which are related to the terms and those others related to the element connectors. Each term and connector may optionally have one constraint or not. The time constraints of terms are of the sort `[start, end, frequency]` and they mean that the term is observed from the start time, to the end time with the frequency indicated. For example, when the term `antidepressant` has a time constraint `[1m, 1w, 24h]` this means alternative things depending on whether it is used in a state element (i.e. the condition of the patient shows that he has been taking antidepressants since 1 month ago, until the last week, every 24 hours), in a branch of a decision element (this branch will be followed only if the patient has been taking antidepressant with the indicated temporal constraint), or in an action element (antidepressant is prescribed with the indicated dosage).

The second sort of time constraints in the SDA* model is related to the element connectors and it has the form `[min, max]`. They are optional and represent delays or durations. For example, a connector `[5d, 1w]` between two elements A and B (i.e. A→B) indicates that the evolution from the element A to the element B will take five days to one week. If only `min` is present, then B is reached only after a `min` time. If only `max` is in the constraint, the meaning is that B will be reached not later than `max` time.

3. Making the SDA* procedural knowledge actionable

Procedural knowledge in the SDA* model has two purposes: (1) provide an explicit representation of long-term therapies that integrate differential treatments that are conditioned both to the patient condition and also to the patient feasible evolutions, and (2) allow the exploitation of this knowledge by a decision support system that could recommend medical actions in the treatment of concrete patients.

This second purpose is achieved with the execution of SDA* procedural knowledge. Given a particular patient, any state the patient satisfies is taken as a feasible starting point of the current patient treatment. One of these states is non-deterministically taken, and all the connectors of these elements to other elements are recursively followed until a state is reached that the patient does not satisfy or a connector is found with a `min` temporal constraint greater than zero. So in the example in figure 1, if the time required to know if an AT treatment is successful or not is between 1 week and 2 weeks (i.e. `[1w,2w]`), a diagnosed patient with headache will get a (re)definition of the AT, but if there is not a minimum time to know whether the AT is successful, then the same patient can be prescribed both an AT and a PT, if he is a good candidate.

4. Examples

In the context of the EU IST K4CARE project (`www.k4care.net`), the SDA* model has been successfully used to represent three alternative sorts of procedural knowledge in medicine [7]: *procedures* (or knowledge about how all the professionals participating in the assistance of patients at home interact and coordinate in order to provide a set of services as patient assessment or follow-up), *formal intervention plans* –FIPs (or medical knowledge about how to treat different diseases as dementia, delirium, depression, diabetes, or hypertension in home care), and *individual intervention plans* (or how knowledge about general treatments is particularized to a specific patient).

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