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# Context-Based Task Ontologies for Clinical Guidelines

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**Abstract.** Evidence-based medicine relies on the execution of clinical practice guidelines and protocols. A great deal of of effort has been invested in the development of various tools which automate the representation and execution of the recommendations contained within such guidelines and protocols by creating Computer Interpretable Guideline Models (CIGMs). Context-based task ontologies (CTOs), based on standard terminology systems like UMLS, form one of the core components of such a model. We have created DAML+OIL-based CTOs for the tasks mentioned in the WHO guideline for hypertension management, drawing comparisons also with other related guidelines. The advantages of CTOs include: contextualization of ontologies, providing ontologies tailored to specific aspects of the phenomena of interest, dividing the complexity involved in creating ontologies into different levels, providing a methodology by means of which the task recommendations contained within guidelines can be integrated into the clinical practices of a health care set-up.

## 1. Introduction

### *1.1 Clinical Practice Guidelines*

Clinical Practice Guidelines (CPGs) are 'systematically developed statements to assist practitioner and patient decisions about appropriate health care for specific clinical circumstances.' [1] Their use in clinical decision-making is intended to improve the outcomes of clinical care [2]. Given that most CPGs are free texts or simple flowcharts, there is a growing need to create Computer Interpretable Guideline Models (CIGMs). For this, however, we require standardized terminologies based on coherent ontologies of clinical activities.

### *1.2. The UMLS Semantic Network and Metathesaurus*

The Unified Medical Language System (UMLS®), designed by the National Library of Medicine, integrates a number of standard medical terminologies into a single unified knowledge representation system [3]. The UMLS Semantic Network consists of 134 Semantic Types and 54 links between these types. These form a graph with a double tree structure, the topmost nodes being '*Entity*' and '*Event*'. The vertices of this graph are the Semantic Types, the edges are the links between them. The corresponding complete graph would contain more than 6000 edges. Even this, however, represents merely a convenient high-level abstraction from the entire UMLS, whose concept repository, the UMLS Metathesaurus (META), includes as of January 2003 some 875,255 concepts and 2.14 million concept names.

### *1.3 DAML + OIL*

While the UMLS provides its terms with associated Semantic Types, one needs a more elaborate ontology in order to use the latter in CIGMs. Among the emerging standards in this field, the DARPA Agent Markup Language and Ontology Interface Language (DAML+OIL) [2] is a proposal for an ontology representation language suitable for these purposes. DAML+OIL is complemented by OilEd, an ontology editor that supports the construction of OIL-based ontologies.

## 2. The UMLS Semantic Network, DAML+OIL and Clinical Practice Guidelines

### *2.1 UMLS Semantic Types for Task-Based Clinical Practice Guidelines*

| UMLS ST | Definition |
|---|---|
| Diagnostic Procedure | A method, procedure or technique used to determine the nature or identity of a disease or disorder. This excludes procedures which are primarily carried out on specimens in a laboratory |
| Laboratory Procedure | A procedure method or technique used to determine the composition, quality, or concentration of a specimen, and which is carried out in a clinical laboratory. Included here are procedures which measure the times and rates of reactions |
| Therapeutic or Preventive Procedure | A procedure method or technique designed to prevent a disease or a disorder, or to improve physical function, or used in the process of treating a disease or injury |

Table 1 Definitions of the 3 UMLS Semantic Types used in the task-based CIGMs.

Based on the manual marking of CPG texts, it has been shown in [4] that most of the actions suggested in CPGs can be mapped into that part of the UMLS terminology which is associated with the Semantic Types *Laboratory Procedure*, *Diagnostic Procedure* and *Therapeutic or Preventive Procedure* (see Table 1), all of which are subclassifications of the Semantic Type *Health Care Activity*.

Other Semantic Types closely associated with *Health Care Activity* but used less frequently in CPGs are: *Educational Activity*, *Governmental or Regulatory Activity* and *Research Activity*, all of which are subclassifications of *Occupational Activity*. *Research Activity*, for example, helps to determine an instance of *Health Care Activity* by contributing its "strength of evidence".

### *2.2 DAML+OIL-Based Ontology of a simplified UMLS Semantic Network*

OilEd [5, 6], the DAML+OIL editor [7], was used in order to specify the relationships between our three selected Semantic Types and the remaining Semantic Types of UMLS. Among all possible relationships (edges), we selected all those adjacent to our three initial vertices together with all edges immediately adjacent to these. By these means we were able to form a

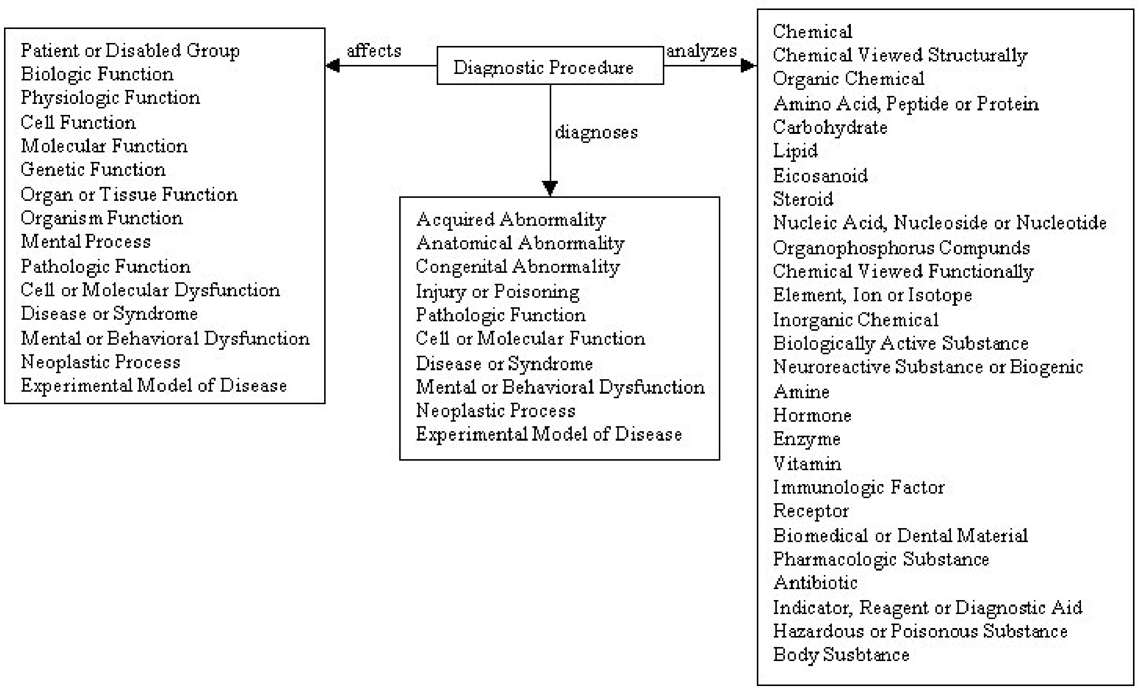


Figure 1 Some adjacency relations of Diagnostic Procedure in UMLS.

Minimal Spanning Subgraph from the original graph of the UMLS Semantic Network, which included all the original vertices but decreased the number of edges to the minimum needed to make a connected subgraph. The adjacency relationships for *Diagnostic Procedure* are shown in Figure 1.

In situations where the relations involved are semantically similar, for example, "analyzes" and "diagnoses", they were combined together to reduce complexity. Since our goal is to produce task-based ontologies, we were able to effect a further simplification by using modifiers such as ‘determination of’ (DOF) as a means for converting classes in other Semantic Types into *Diagnostic Procedures*. For example “Proteinuria” (figure 2), is either a laboratory or test result or a disease or syndrome. None of these is a *Health Care Activity*. Hence we use the DOF operator in order to incorporate “Proteinuria” into our CPG ontology (which is restricted to the Semantic Type *Health Care Activity*) via the heading: “Determination of Proteinuria” (DOF Proteinuria).

Term – Proteinuria

Semantic Type – *Laboratory or Test Result, Disease or Syndrome*

    Operator – DOF (Determination of)

Term – DOF Proteinuria

New Semantic Type – *Laboratory Procedure*

Figure 2 Mapping for the term “Proteinuria”.

### *2.3 DAML+OIL Ontology of Laboratory Procedures*

Our design methodology was, first, to construct a basic framework of classes and slots for the CPG domain, starting with the two UMLS superclasses ‘*Entity*’ and ‘*Event*’, and then to incrementally extend and refine this framework by adding new classes and slots together with associated definitions. For example, to represent the fact that *Laboratory Procedure* analyzes (has as target) *Chemical*, the class and slot definitions in figure 3 were used. A *Laboratory Procedure* is a subclass of the class of *Health Care Activities* and a *Chemical* is a subclass of the class of *Substances*; a *Laboratory Procedure* analyzes a *Chemical* and a *Chemical* is analyzed by a *Laboratory Procedure*.

class-def defined *Laboratory Procedure*

    subclass-of *Health Care Activity*

    slot-constraint analyzes

        value-type *Chemical*

class def defined *Chemical*

    subclass-of *Substance*

slot-def analyzes

    inverse is analyzed by

Figure 3 Frame based approach for Laboratory Procedure that analyzes Chemicals

However, the problem with the frame-based approach is that it can specify only certain relations between the types of classes involved. Thus, representing *Laboratory Procedure* as a subclass of *Health Care Activity* does not give any insight into whether *Laboratory Procedure* is the only subclass of *Health Care Activity* and whether completion of the former would also mean the completion of the latter.

These issues can be addressed by using mereology or the theory of relations between parts and wholes (see [8]). We depict *Laboratory Procedure* as a part-of *Health Care Activities involving Laboratory Procedure* (that is each instance of *Laboratory Procedure* is a part of some instance of *Health Care Avtivities involving Laboratory Procedure)*. This approach allows us to specify whether *Laboratory Procedure* is or is not the only part-of a given *Health Care Activity*, that is, if (*Health Care Activity – Laboratory Procedure*) is or is not empty. (Here '–' symbolizes the mereological subtraction operator; for the formal treatment of these matters see [9], [10].)

One way to represent the mereologized partition in DAML+OIL consists in defining the ontology as follows:

```
class-def defined Laboratory Procedure
        subclass-of Health Care Activity
        slot-constraint part-of
                value-type Health Care Activities involving Laboratory Procedures
        slot-constraint analyzes
                value-type Chemical

class-def defined Diagnostic Procedure
        subclass-of Health Care Activity
        slot-constraint part-of
                value_type Health Care Activities involving Diagnostic Procedure

class-def defined Therapeutic and Preventive Procedure
        subclass-of Health Care Activity
        slot-constraint part-of
                value-type Health Care Activities involving Therapeutic and Preventive Procedure

class-def defined Health Care Activity
        slot-constraint part-of
                value-type Health Care Activities involving Laboratory Procedures
        slot-constraint part-of
                value-type Health Care Activities involving Diagnostic Procedure
        slot-constraint part-of
                value-type Health Care Activities involving Therapeutic and Preventive Procedure

slot-def analyse
        inverse is-analyzed_by


slot-def  part-of
        inverse has_part

disjoint
        Laboratory Procedure
        Diagnostic Procedure
        Therapeutic and Preventive Procedure

class-def defined Health Care Activities

        disjointUnionOf

                Health Care Activities involving Laboratory Procedures

                Health Care Activities involving Diagnostic Procedure

                Health Care Activities involving Therapeutic and Preventive Procedure
```

It is important to notice that the last construct determines an exhaustive partition in the sense that it ensures that "Health Care Activities" us composed by and only by: "Health Care Activities involving Laboratory Procedures", "Health Care Activities involving Diagnostic Procedure" and "Health Care Activities involving Therapeutic and Preventive Procedure". Moreover it ensures that "Health Care Activities involving Laboratory Procedures" includes at least a *Laboratory Procedure* but can contain also other kinds of *Health Care Activities* such as *Diagnostic Procedures* or *Thereapeutic Procedures*.

### *2.4 WHO Hypertension Guideline*

The CPG for the Management of Hypertension prepared in 1999 by the WHO International Society of Hypertension was used to create CTOs [11].

## 3. Contextualizing Task-Based Ontologies

### *3.1 Generic Context based on UMLS*

CTOs involve multiple ontologies reflecting the multiple contexts in which guidelines are involved. Given tasks do not necessarily have the same typology within different contexts. Thus within the CTO that is dictated by the context of the UMLS Semantic Network tasks are linked only via the is-a and part-of relations which Network itself contains, which means only those relations which pertain to their belonging to the three Semantic Types mentioned above, along the lines illustrated in figure (4). The UMLS Semantic Network does not specify the task-subtask hierarchy associated with any specific guideline. Rather, it provides only the generic context for more detailed ontologies.

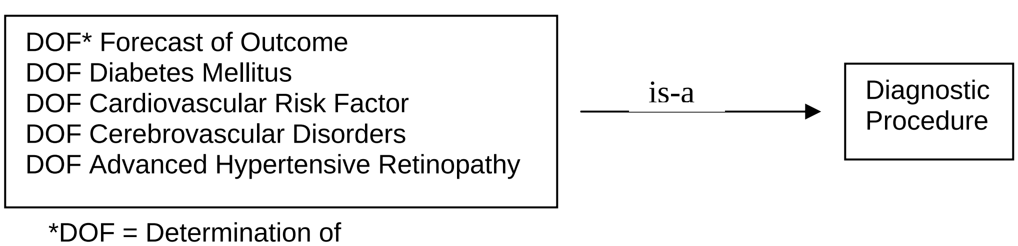


Figure 4 A fragment of a Context-Based Task Ontology within UMLS.

Each of the procedures mentioned in this figure can itself serve as the basis of a more fine-grained partition based on recognizing constituent parts, as discussed in [12, 13]. Thus we can distinguish between *Diagnostic Procedures involving Forecast of Outcome* and *Diagnostic Procedures not involving Forecast of Outcome*, or between *Diagnostic Procedures involving Diabetes Mellitus* and *Diagnostic Procedures not involving Diabetes Mellitusm*, and so on.

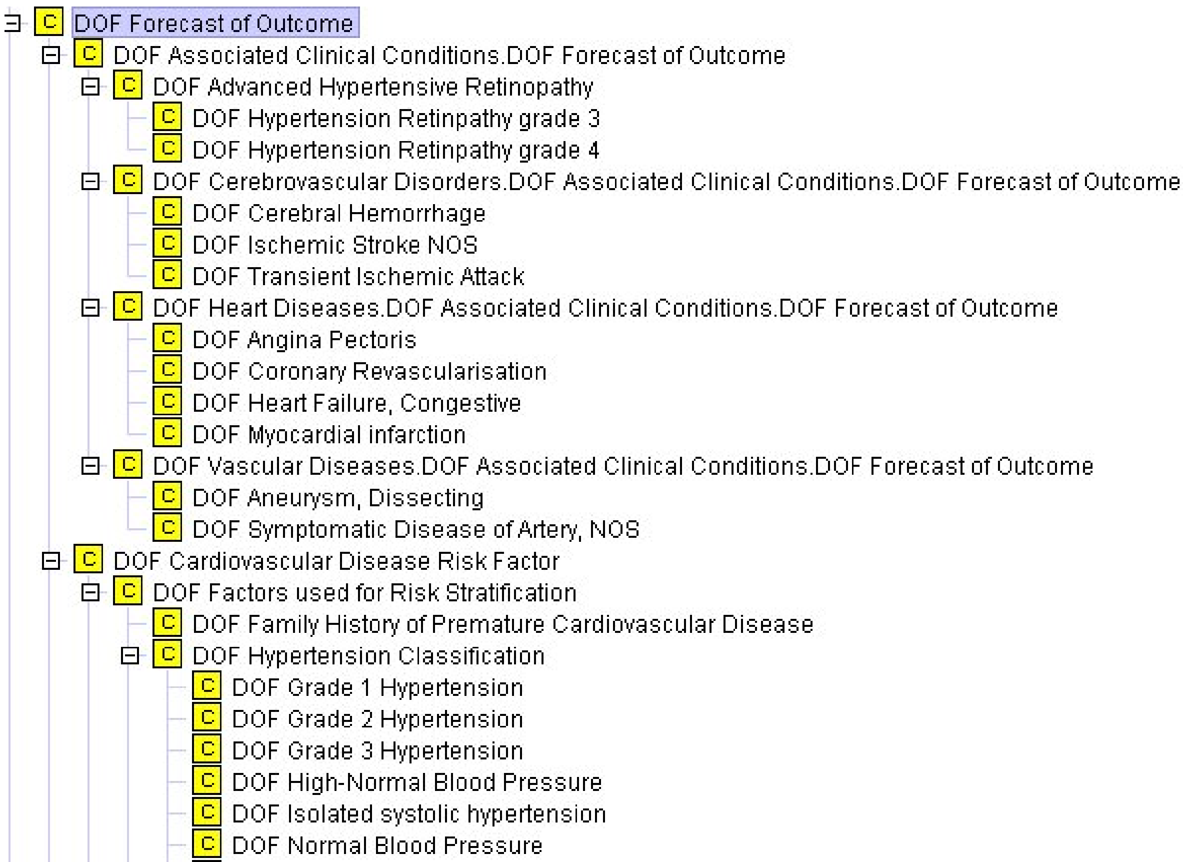


Figure 5 Context-specific task hierarchy based on WHO guideline on hypertension

### *3.2 Specific context based on the guideline*

The task-subtask hierarchy pertinent to the WHO guideline is illustrated in Figure 5. The *DOF Forecast of Outcome* that is a type of *Diagnostic Procedure* has to be understood here as *DOF Forecast of Outcome of Hypertension* since we are working in the context of a hypertension guideline. We then have:

DOF Forecast of Outcome involved in Hypertension is-a Diagnostic Procedure

and

DOF Forecast of Outcome of Hypertension is-part-of Diagnostic Procedures involved in Hypertension

A representation of this type tells us in which context given subtasks carried out, for instance, “Determination of Cerebral Hemorrhage” is a type of and is out carried within the context of “Determination of Cerebrovascular Disorders”, which, in turn, is a type of and is carried out within the context of “Diagnostic Procedure” (fig. 6).

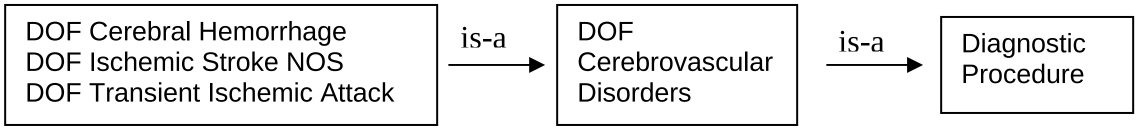


Figure 6 Guideline-specific CTO

This representation can be further extended by means of part-of relations:

DOF Cerebral Hemorrhage part-of DOF Cerebrovascular Disorders involving DOF Cerebral Hemorrhage (partition: DOF Cerebral Hemorrhage)
DOF Ischemic Stroke NOS part-of DOF Cerebrovascular Disorders involving Ischemic Stroke NOS (partition: Ischemic Stroke NOS)
DOF Transient Ischemic Attack part-of DOF Cerebrovascular Disorders involving DOF Transient Ischemic Attack (partition: Transient Ischemic Attack)

Typological relations are specified based on the partitions above as follows,

DOF Cerebrovascular Disorders involving DOF Cerebral Hemorrhage is-a DOF Cerebrovascular Disorders
DOF Cerebrovascular Disorders involving Ischemic Stroke NOS (nitric oxide synthase) is-a DOF Cerebrovascular Disorders
DOF Cerebrovascular Disorders involving DOF Transient Ischemic Attack is-a DOF Cerebrovascular Disorders

And these lead to,

DOF Cerebrovascular Disorders involving DOF Cerebral Hemorrhage ∪ DOF Cerebrovascular Disorders involving Ischemic Stroke NOS ∪ DOF Cerebrovascular Disorders involving DOF Transient Ischemic Attack = DOF Cerebrovascular Disorders

where '∪' signifies the operation of taking unions of classes..

The latter represents the task in relation to its subtasks – those parts whose completion is necessary for the completion of the task. In this case, DOF Cerebrovascular Disorders has been classified using a series of partitions for each of which we define the involvement and non-involvement of the subtask. What is shown above are the relations where the subtask is involved in the task and on similar lines, there are relations where subtasks are not involved in the task. In the above cases, they include:

DOF Cerebrovascular Disorders not involving DOF Cerebral Hemorrhage is-a DOF Cerebrovascular Disorders

DOF Cerebrovascular Disorders not involving Ischemic Stroke NOS is-a DOF Cerebrovascular Disorders

DOF Cerebrovascular Disorders not involving DOF Transient Ischemic Attack is-a DOF Cerebrovascular Disorders

Adding these negative clauses means that task representations can be more specific. They also allow us to assert that two classes have no class-theoretic intersection, for example as follows:

DOF Cerebrovascular Disorders involving DOF Transient Ischemic Attack ∩ DOF Cerebrovascular Disorders not involving DOF Transient Ischemic Attack = ∅ (null)

DOF Cerebrovascular Disorders involving DOF Transient Ischemic Attack ∪ DOF Cerebrovascular Disorders not involving DOF Transient Ischemic Attack = DOF Cerebrovascular Disorders

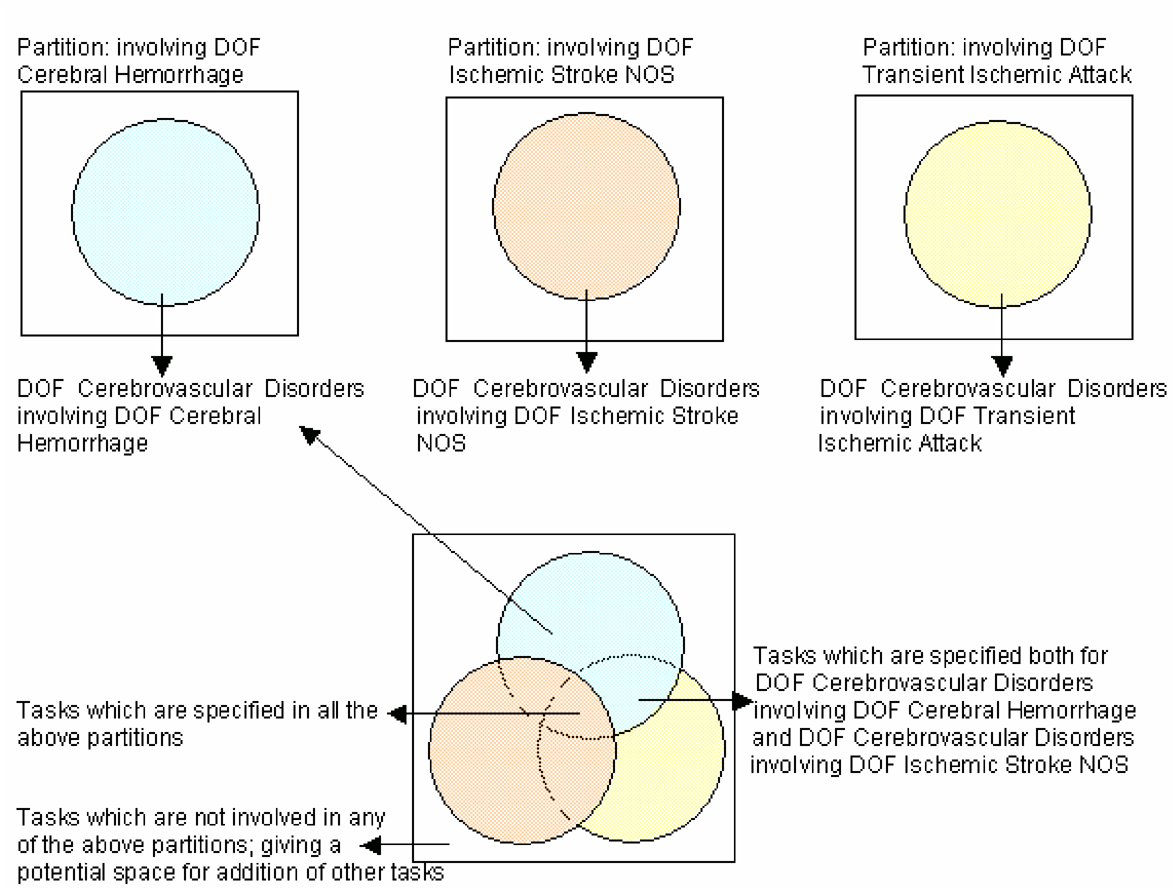


Figure 7 Partitions with Venn diagrams.

When such relations are defined within a given partition, we can exploit our machinery for represenating the positive and negative involvements and unions in order to specify given tasks relative to given contexts in a very precise manner. We can also use Venn diagram representations as in Figure 7, where the squares in each case represent the relevant universe of discourse, the circles represent given DOF-classes, and the empty spaces represent those portions of the task space which are not involved in any subtasks considered within the respective partitions. This leaves room for the addition of new tasks, which might needed when we move out of the context as strictly defined by the current guideline. (See the treatment of empty space in [13].) Overlaps signify cases where a single subtask is carried out in the implementation of a plurality of larger tasks within a health care setup; for example patient history taking forms part of all the three tasks considered in the above. Some of the higherlevel entities comprehended by guideline representation systems such as Guide [14, 15] are modeled as *intentions* in guideline modeling standards like Asbru [16] or as *plans* in Proforma [17]. Here, however, we do not distinguish between intentions, tasks and plans, though our use of the framework of granular partitions means that this and similar distinctions can easily be introduced as a refinement within our theory.

### *3.3 Various views to interpret and implement clinical practice guidelines*

Clinical practice guidelines (CPGs) are composed always in relation to a generic clinical context. However each specific implementing health care organization will look at each given CPG from different points of view. Thus an internal medicine team would need to supplement them with an ontology constructed from the point of view of implementation, an ontology which would be more closely aligned with the workflow practices in the specific health care set-up. For example, Medical History Taking can form a part of DOF Cerebrovascular Diseases, as a result of which the following relations are created:

Medical History Taking involved in DOF Cerebrovascular Diseases part-of DOF Cerebrovascular Diseases involving Medical History Taking (Partition: Medical History Taking)

DOF Cerebrovascular Diseases involved in Medical History Taking part-of Medical History Taking involving DOF Cerebrovascular Diseases (Partition: DOF Cerebrovascular Diseases)

where ‘A involved in B’ and ‘B involving A’ are noun phrases designating, respectively, the class of those As existing as parts of Bs, and the class of those Bs existing with As as parts. Similar relations apply also to the subtasks. Thus for DOF Transient Ischemic Attack, the relations created are:

Medical History Taking involved in DOF Transient Ischemic Attack part-of DOF Transient Ischemic Attack involving Medical History Taking (Partition: DOF Transient Ischemic Attack)

DOF Transient Ischemic Attack involved in Medical History Taking part-of Medical History Taking involving DOF Transient Ischemic Attack (Partition: DOF Medical History Taking)

The parthood relations are maintained as before and thus:

Medical History Taking involved in DOF Transient Ischemic Attack part-of DOF Cerebrovascular Disorders involving Medical History Taking (Partition: Medical History Taking)

This reveals the existence of finite chains of parthood relations within the partitions at issue. It also shows how the actual task implementation is linked to the semantic relationships present in the guideline. It shows also how a plurality of ontologies or classification schemes can be created reflecting the different contexts in which the ontologies need to be applied.

There can be other views: nursing staff will have a different task ontology for the hypertension guideline, which would also include slots for inpatient ward care for complicated cases, for home visits, counselling, and so on.

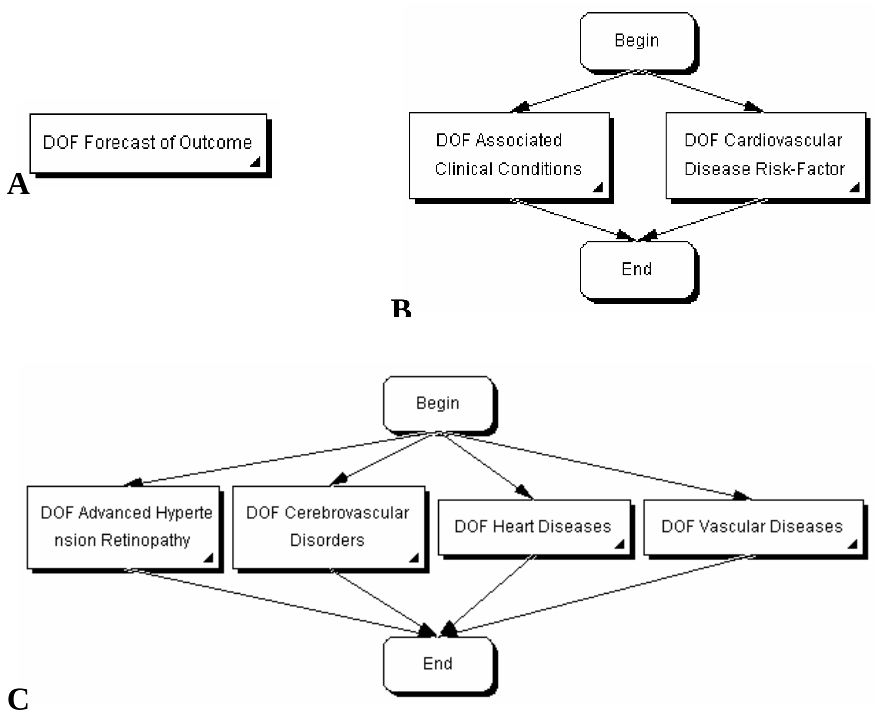


Figure 8 Tasks represented in the Guide formalism

### *3.4 CTOs and clinical practice guidelines formalism*

A guideline serves as the basis for the creation of a number of ontologies within a given health care set-up and these ontologies can then be used to support reasoning about tasks and subtasks which are required by those implementing the guideline from different points of view. The framework sketched above does not provide the resources for representing time schedule and other details related to the particular contexts of implementation. For these purposes it will need to be supplemented by other types of machinery for translating CPG recommendation into a computerized format, for example by the Guide formalism.REF

Referring to figure 2 we can use our framework to build a flow of tasks in the Guide formalism (fig. 8). First of all, we define a complex task called “DOF Forecast of Outcome” (A). The bottom-right black triangle means that the task is complex and it will be defined by a hierarchy of tasks and subtasks (in Guide each expansion is called a level). Sublevels (B, C) specify all the tasks involved in the main process. All the information related to time and to the order of execution may be specified in Guide. In the case of hypertension diagnosis all the tasks can be performed in parallel as no particular order of execution or time schedule is required. Moreover the situation is quite simple, because all the DOF activities defined in the “forecast” are concentrated in a particular part of the guideline.

A different situation arises in the management of hypertension disease. In this case, the sequence of the tasks and the conditional dependency the tasks involved are more important and more complex.

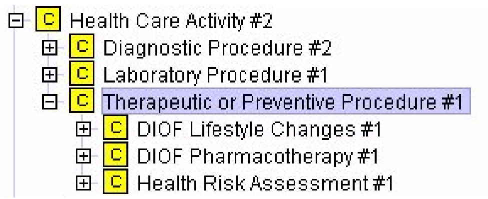


Figure 9 CTO regarding Health Care Activity related to the WHO Hypertension guideline.

Let us consider a portion of the context-specific ontology regarding the health care activities involved in hypertension management (fig. 9). They are formally defined, but for purposes of implementation in a given health care set-up we need to add information related to the sequence of the tasks to be performed and to the time schedule. “Laboratory Procedure”, within the most generic task ontology associated with the given guideline includes all the sorts of laboratory procedures referred to within the guideline as a whole, and it is obvious that these are widely spread along the temporal axis in the management of hypertension.

The left part of figure 10 depictsa synchronization block (labeled “T”) that recommends the initiation of the subsequent tasks at some specific point in time. A lifestyle modification is always recommended, since otherwise the success of the pharmacotheraphy will be depend too severely on the risk group to which the individual patient belongs. The same parts of the ontology can be represented also in the right part of the figure, capturing the site specific context BUT THERE IS NOTHING ABOUT SITE THERE!, where the communication of recommended lifestyle changes is usually carried out as the first task in the treatment. While the ontology is the same in both cases, the time schedule and possibly the decision processes involved will differ. CONTRAST BETWEEN THE TWO FIGURES NOT CLEAR. WHAT IS ‘DET’?

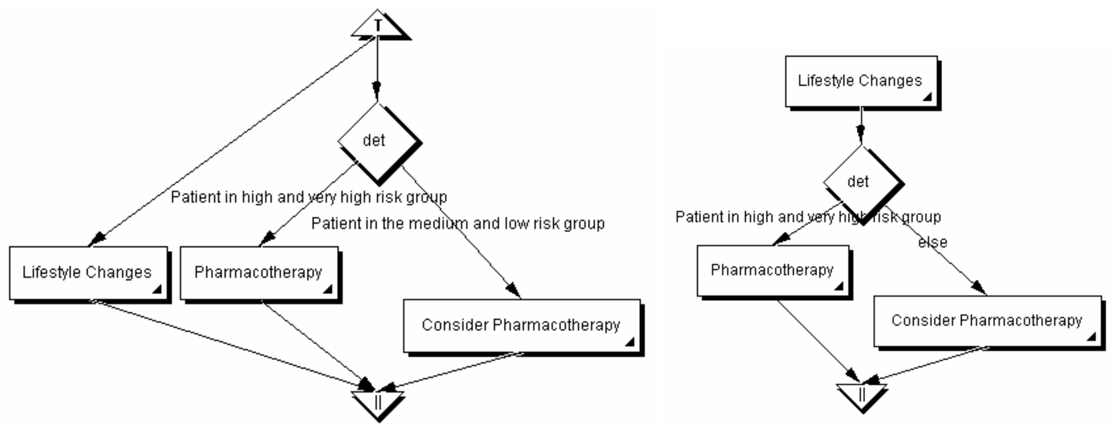


Figure 10 This has Corsider Pharmacotherapy – please fix Two different formalizations of the same steps of the WHO Hypertension guideline

In this way context-specific ontologies can also be useful to check Guide formalism consistency. When the flows are formalized, we can check if all the concepts expressed in the ontology are present and are properly managed.

### *3.5 Multiple clinical practice guidelines CTOs merging*

Finally a challenging topic is that of merging different CPGs together. The merging process is complex and it is related to both ontologies and time flows. In fact it is not sufficient to understand that given tasks present in two different CPGs are similar; it is important to understand also what their respective time schedules are. Clearly, successful merging of ontologies needs careful attention to temporal issues.


Figure 11 Example of CTO for Diabetes Mellitus guideline.

Ontologies can help us to understand the relations between tasks involved in the execution of different clinical practice guidelines. If, for examplea, a patient is diabetic and hypertensive, then there are at least two possible CPGs that can be taken into consideration. To manage such cases, we used the Prompt suite of tools for multiple-ontology management that is provided as an extension to the Protégé ontology-editing environment in the form of a set of plug-ins. The iPrompt algorithm takes as input two ontologies and guides the user in the creation of one merged ontology as output. The slots of the classes merged are retained as they are within the original ontologies. Using these tools, the overlapping portions of hypertension and diabetes CPG were mapped and further relations created within the tasks originally existing within the two separate ontologies [18].

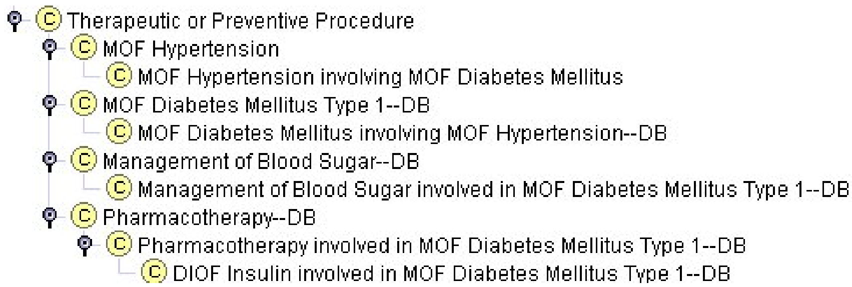


Figure 12 Diabetes Mellitus guideline CTO merged with a piece of Hypertension guideline CTO

## 4 Advantages and Disadvantages of CTOs

The advantages of context-based task ontologies include:

1. The CTOs are able do justice to the fact that the same clinical task can be performed within different contexts and to the fact that the significance of a given task within those different contexts may itself be different.
2. The CTOs do not provide some unique ontology structure. Rather, they reflect the fact that there are different views shared among the different specialists involved in the implementation of clinical practice guidelines.
3. CTOs separate the specification of a task without temporal annotation and the carrying out of a task with temporal annotation. Task ontologies are thus divided into two levels, allowing the separation of the issues pertaining to the generic guideline from those pertaining to implementation within the health care environment.
4. The CTO framework provides a robust methodology which can form the basis of integration of clinical guideline recommendations with the actual clinical practices in a health care setup.
5. CTOs provide a basis for merging various task ontologies from different clinical guidelines. This can be useful in management of patients with multiple clinical disorders.
6. CTOs are application independent and thus they can be used by the various tools which create Computer Interpretable Guideline Models.

On the other hand, the disadvantages of CTOs include:

1. Specification of parthood and typological relations is time-consuming and it is difficult to automate this process.
2. Creation of CTOs needs the help of experts from the relevant disciplinary fields/contexts.
3. Providing multiple ontologies is a lenghty task and the execution of computer-supervised comparisons and mergers is difficult.

## 5 Concluding Remarks

The creation and execution of CTOs involves a series of steps, including interpretation of the CPG, the formalization of the relations holding between the entities referred to in the guideline text, creation of ontologies, modelling the guideline model modelling the model! THAT IS GOOD. AND THEN WE CAN MODEL THE MODEL OF THE MODEL ! ! in an authoring enviroment, merging various CPGs based on context, and so on. Further work will need to be done towards formalization of relations and in particular, merging of task-ontologies and the execution paths of the task. THE CONCLUSION IS A BIT LAME. PLEASE IMPROVE OR DELETE. CAN YOU ADD CROSS-REFERENCES TO OUR OTHER PAPER IN THIS VOLUME:
http://ontology.buffalo.edu/medo/WorkflowFramework.pdf

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