An Ontological Analysis of Surgical Deeds

A. Rossi Mori [a], A. Gangemi [a], G. Steve [a], F. Consorti [b], E. Galeazzi [c]

[a] Reparto Informatica Medica, Istituto Tecnologie Biomediche, CNR , Roma, Italy [1]
[b] IV Clin. Chirurgica and [c] Dottorato Informatica Medica, Univ. La Sapienza, Roma, Italy

We collected a set of words, suffixes, and idioms regarding actions in surgical procedures, ie. "deeds" as defined in a CEN European Prestandard; we then searched for their definitions in different authoritative sources and we performed an ontological analysis of this material according to the ONIONS methodology. The result was a formal model on surgical actions, as an extension of our previous model ON8.5, using Ontolingua with "frame ontology". We worked out criteria to assist domain experts in organizing hierarchies on surgical actions, according to points of view on structural, instrumental and functional properties.

1. Introduction

In this paper we present an analysis of surgical deeds, which is the outcome of an original approach to ontology, involving:
1) systematically capturing taxonomic knowledge from authoritative sources,
2) treating such knowledge by a methodology using linguistic and conceptual tools,
3) representing it formally by i) a set of ontologically committed primitives and ii) a set of axioms on those primitives.

1.1. "Surgical Deed" and "Surgical Procedure" in CEN ENV 1828

The starting point for our analysis has been the European Prestandard CEN ENV1828 [CEN95]; it defines *surgical deed* as "deed which can be done by the operator to the patient's body during the surgical procedure", with the note that the surgical deed "shall be described without reference to any specific human anatomy or interventional equipment".
It provides about 60 examples of deeds, arranged in 14 clusters (examples of clusters are: to open, to pass through, to install; examples of deeds included in the cluster "to install" are: to implant, to inject, to insert, to transfuse, to transplant). In existing classifications and nomenclatures, concepts of deeds exceeds 500 (cf. [Bernauer96]).
The Prestandard also introduces a frame for *surgical procedure* (table 1).

The CEN distinction between *procedure* and *deed* mainly depends on the empirical criterion of *instantiatability*: if a surgical "action" is specific to a certain structure (human anatomy or interventional equipment) it is a procedure, otherwise it is a deed.
On the other hand, most actions are naturally performed only on certain *kinds* of structures, thus, which is the sufficient instantiation for an action to be a procedure? (or the sufficient generality to be a deed?). The criterion of *sufficiency* is obviously left to intuition. Moreover, as our Ontolingua translation shows, CEN's constraints depend on standalone categories, which are not parts of any formal theory.
Starting from these difficulties, we defined an ontology of surgical actions, providing a theory to explicitly motivate categorial choices as well as criteria for instantiation.
We also show that a comprehensive and consistent theory greatly enhances the definition of constraints for classifying the kinds of actions carried out by surgeons.

---

[1] send mail to ARM, viale Marx 15, I-00137 Roma; angelo@color.irmkant.rm.cnr.it

Table 1. Definition of surgical procedure in CEN ENV 1828, here translated in Ontolingua [Gruber93] as a standalone theory, ie. not as a part of any general formal theory

```
(define-class cen-surgical-procedure (?c-sp)
"a surgical procedure is determined in CEN by some instance of human anatomy,
pathology, or interventional equipment, which may act as direct or indirect object, as
well as means. They include at least one direct object, as well as at least one
instance of human anatomy, and has deeds made during it"
  :def  (and (exists (?d ?x ?y)
                     (and (deed ?d)
                          (during ?d ?c-sp)
                          (has-direct-object ?c-sp ?x)
                          (or (human-anatomy ?x)
                              (pathology ?x)
                              (interventional-equipment ?x))
                          (human-anatomy ?y)))
             (=> (has-indirect-object ?c-sp ?z)
                 (or (human-anatomy ?z)
                     (pathology ?z)
                     (interventional-equipment ?z)))
             (=> (has-means ?c-sp ?z)
                 (or (human-anatomy ?z)
                     (pathology ?z)
                     (interventional-equipment ?z)))))
```

1.2. Relevance of Ontology in Formal Models

The project GALEN-IN-USE [Rossi Mori95, GALEN92-96] is populating a formal model on surgical procedures by a cooperative effort; experts from 4 centers in Europe (including one in Rome) are building a comprehensive model from rubrics of various coding system, in collaboration with Victoria University in Manchester.

In our center, we initially instructed domain experts to use a limited list of well-defined deeds and to force each new word they were encountering into one existing concept; but they felt that rule too limiting on their expressiveness. We decided then to let experts be free to introduce any new deed, but we also asked to place them in the context of existing ones, ie, to put each new deeds as subordinate to one or more existing ones possibly working out the differences towards them.

At the same time, we started to build a robust ontology on deeds, to formally describe similarities and differences among available concepts and towards the new ones.

Parallel work on this issue was made by another partner in the GALEN-IN-USE Project [Bernauer96], merging the current "Generic Process Model" with deeds that could be identified in the German version of ICPM [Kolodzig94], yielding a structure organizing deeds under about 20 major aspects. However, many deeds can be organized under different legitimate aspects; eg. *smoothing* is a kind of *removing* and *reshaping*; *wiring* is a kind of *connecting*, *immobilising* and *device-application*.

A major issue is therefore to adopt a well-structured and stable representation of deeds, which can be only obtained by a thorough understanding of original intended meaning of deeds within a framework of general theoretical *paradigms*.

We maintain that a correct approach for this issue is *ontological analysis and integration*, which are supported, for example, by our ONIONS methodology [for ontology in general: Guarino95; for ONIONS: Steve96a, Gangemi96a; for ontology and KB: [van Heijst97]; for ontology libraries in medicine: [Falasconi94]).

Moreover, an ontological methodology may help clarifying the choice of primitives of representation (what concepts are to be modelled as predicates?, what is a role vs. a sort or a property?, cf. [Guarino94, Steve96b]); finally, tangleness of collected

hierarchies is another point of attack for ontological integration, which can define flexible criteria of identity according to different aspects, viewpoints, contexts.

1.3. Relevance of a Methodology for Ontological Analysis

In current ontology literature, few Authors address the problem of defining a methodology for ontological analysis, being mostly concerned with representational issues (for a critique: [Gangemi96a]; for some work on methodology: [Uschold96, Steve96b]). Indeed, there are well defined and used methodologies for knowledge acquisition [eg, Schreiber92, Shadbolt93], but these are meant mainly for acquiring task-specific, operational problem-solving knowledge rather than multi-functional domain knowledge, ie. the purpose of ontological *analysis*. Moreover, they do not treat at all ontological *integration* of knowledge sources. In the following we show why we need analysis and integration of sources.

It is relatively easy to envisage criteria to group a large number of deeds and to relate them, at least in a first approximation; eg, using as characteristics: (1) "movement with respect to organism", and (2) "physical state of the moved substance", we have:

	taking away from organism	*insert into organism*
fluid	drainage, aspiration, ...	instilling, puncturing, inject, transfuse, ...
solid	remove, extirpate, -ectomy, ...	install, implant, transplant, ...

But this method is not appropriate to produce a really stable and complete structure, even if it provides an useful understanding and a preliminary organization of the field.

A more precise and analytic process has to be followed, extracting principles and primitives that are ontologically grounded to domain-independent paradigms, in order to be coherent with a comprehensive and stable framework. Criteria such as *taking away, inserting, solid structure*, have to be put in the context of general theories at several degrees, for example *taking away* calls for a theory describing *movement*, and —more generally— *actions, intentional events, processes*. The taxonomy of theories which allow integration constitutes a hierarchy of semantic fields structured by some semantic operators (logically, a hierarchy of sorts and relations, and a set of axioms; conceptually, a set of concepts and a set of relations for defining concepts).

This procedure of understanding and integrating criteria in an ontological framework is part of a comprehensive methodology of ontological analysis, briefly presented in § 2.

2. Materials and Methods

Building the ontological model on surgical deeds corresponds, for our group, to two parallel activities:

- to extend the branch on surgical procedures of our integrated model for medical taxonomic sources, ON8.5 [Steve96b];
- to adapt our methodology for ontological analysis, ONIONS [Gangemi95], to the particular features of this study, integrating it with the CEN-MOSE approach [CEN96, Rossi Mori96a].

Deeds are expressed by single words (with the exception of a few suffixes or idioms), because all explicit information about particular structures, devices and functions was removed from the phrases in the original corpora, according to the definition of "surgical deed" in CEN ENV 1828 (see § 1.1).

We had consequently the problem to preserve a *systematic, reproducible approach* to compositional analysis, compatibly and in parallel to our methodology for ontological analysis.

Therefore we describe in this paragraph how we used two kinds of original materials:
• the top level of ON8.5, generated trough the ONIONS methodology;
• various terminological corpora —sources of phrases and authoritative sources of definitions— from which we arranged three kinds of intermediate resources:

- a list of deeds;
- a collection of definitions for a subset of these deeds;
- a hierarchy of deeds, made according to definitions and extended by using knowedge from experts.

2.1. Terminological and Definitional Sources

a) sources for deeds: ENV 1828 [CEN95] and major coding systems: ICD-9-CM [HCFA88], ICD-10-PCS [Averill95], SNOMED Int'l [Rothwell93].
Suffixes were isolated when reasonably independent, eg, *-ectomy*, *-tomy*, *-plasty*.
We kept all kinds of actions, even very specific, eg, *fundoplication*, *cannulating*.
We made no distinction on grammatical forms of a word, ie, verbal forms (eg, infinitive, past participle), suffixes, noun phrases (eg, verbal substantive, deverbal noun) were considered as the same deed.
We collected about 200 deeds, from which we selected only the ones regarding actual actions performed by surgeons; ie, we did not consider:
1 meta-expressions on enactment of procedures, eg, *terminate*, *cancel*, *suspend*, *repeat*
2 too general actions, eg, *change*, *operation*;
3 healthcare activities, eg, *therapy*, *prevent*, *diagnosis*, *control* (see § 3.2).

b) sources for definitions or explicit interpretation hints:
- a systematic source on surgery, ie, an early report on ICD-10-PCS [Averill95];
- dictionaries of medicine [Dorland's94, Wiley86, Stedman's95]
- a computer-based dictionary of English, hierarchically structured [Wordnet96]
- the English dictionary adopted for CEN standards [Oxford95]

Only definitions relevant to surgery were considered, for a total of 142 definitions.

c) additional informal knowledge: we extracted further knowledge, embedded in implicit or explicit organization of textbooks and coding systems, specially SNOMED, also by discussions with domain experts in Rome.

2.2. Methods

Our methodology is not automatic nor objective, but it defines how to analyze the ontology of the sources and how to build an integrated formal ontologic model.

Preliminary Phase

We extracted words, suffixes and idioms of deeds from various coding systems (§2.1a); they are preferential sources for terminological phrases, because in principle they are authoritative, intersubjective, maintained, complete of relevant items and tested by users. For most deeds we found adequate definitions into dictionaries (§2.1b); we added to our list of deeds also the superordinate ones used in these definitions. In some source we were able to extract partial hierarchies. When we encountered more than one sense for the same word, we introduced new entries; analogously, when our experts were not able to see any difference between the meanings of two words, we collapsed them provisionally into a single entry, so that each entry in our list represents a precise, distinguishable concept within each source respectively.
Results of this phase are: a list of deeds, a collection of local definitions, and some local and temporary hierarchies among deeds.

Extension and Refinement Phase
Extension and iterative refinement of the model are the output of three activities performed in parallel and deeply depending on each other.

Activity A: maintenance of hierarchy. We used the differentiating characteristics from available definitions —and informal discussions with the experts— to arrange the related subset of deeds in a hierarchy and to revise it when appropriate according to feedback from the other two activities. For remaining deeds, we asked the experts to place them in the above hierarchy and to make explicit, if possible, differentiating characteristics between parents and children. Difficult and intriguing issues from the three activities were discussed also with external experts. Results were twofold: the hierarchy and the set of *descriptors* (differentiating characteristics) used to organize it.

Activity B: systematization according to the ontological model ON8.5. The model ON8.5 has been developed through our ONIONS methodology from a set of medical taxonomic sources (eg, SNOMED, ICD-10, UMLS). Descriptors from Activity A have been, when possible, directly integrated in the common framework of general theories used in previous top-level model building; otherwise, they had been referred to additional theories, implying a model rearrangement. Such theories are not considered in every part, but only to the extent they provide the minimal structure for creating a framework which allows for integration of criteria. Extension of ON8.5 implies the ontological opportunity of introducing some new connective concepts, eg. a local top-level for surgical deeds, which makes such distinctions as mereologically-oriented vs. topologically-oriented deeds, or function-changing vs. morphology-changing deeds.

Activity C: maintenance and refinement of formal model. According to previous work, we organized the branch on surgical procedures in sorts, relations (inheritable or not), properties, roles, contexts, description frames, viewpoints, general and contextual rules. The model is currently represented in order-sorted logic and Ontolingua. We used representation primitive categories of ON8.5, which commits to structural concepts, structuring concepts, roles (for details: [Steve96b]). Tests are being carried out to implement this ontology in a snepslog-based [Shapiro92] language.

3. Results
The core result of our process of analysis consist in the extension of ON8.5; the current Ontolingua model covers about one hundred deeds. *Surgical procedure* in CEN ENV1828 corresponds to "surgical-procedure" in ON8.5, and *surgical deed* roughly corresponds to "surgical-telic-event" (§ 3.1) or "surgical-act" (§ 3.3).
Here we also introduce the organizing criteria to explain and order such deeds, as derived from our ontological model (§ 3.2).

3.1 Definition of Surgical Telic Event in the model ON8.5
The application of ON8.5 top-level has provided the formal definition of telic events involved in surgical procedures (table 2).
This definition includes all partial definitions inherited from being a sub-class of:

```
: TelicEvent: Action: Activity: Process: Object.
```

The ontology of telic events requires ordering situations temporally as well as contextualizing them by the second-order predicate IST (*is-true-in*, [McCarthy94]).
This has been implemented through a metalinguistic approach, which allows quantifiers to range over a logical expression taken to be true within a context.

Table 2. Formal definition, expressed in Ontolingua, of surgical-telic-event *in ON8.5. Predicates preceded by a ° are properties (unary predicates representing structuring concepts), while those preceded by a * are roles:*

```
(define-class surgical-telic-event (?ste)
"surgical telic events are dynamic objects in the biologic world, have biologic or
material structures as substrates within a time interval, are carried out by surgeons,
have signs or conditions as goals, are constitutive phases of surgical procedures, have
inherent surgical acts, may use instruments or means, and typically carry out a change
along two or more consecutive situations"
  :def (and (telic-event ?ste)
            (exists (?msign ?cond ?surg ?str ?mdev ?mc1 ?mc2 ?s1 ?s2 ?cha ?pha ?ha ?*sa)
                    (and  (medical-sign ?msign) (*physical-agent ?pha)
                          (condition ?cond) (*surgeon ?surg) (*surgical-act? *sa)
                          (or (material-structure ?str)
                              (biologic-structure ?str))
                          (medical-device ?mdev) (healthcare-activity ?ha)
                          (situation ?s1) (situation ?s2) (*chemical-agent ?cha)
                          (meta-concept ?mc1) (meta-concept ?mc2)
                          (°intervallistic ?ste) (°dynamic ?ste)
                          (°depends-on-biologic-layer ?ste)
                          (is-constitutive-phase-of ?ste ?ha)
                          (has-constitutive-phase ?ste ?*sa)
                          (performs ?surg ?ste)
                          (embodies ?str ?ste)
                          (or (is-instrumental-for ?mdev ?ste)
                              (is-instrumental-for ?cha ?ste)
                              (is-instrumental-for ?pha ?ste)
                          (or (is-goal-of ?msign ?ste)
                              (is-goal-of ?cond ?ste))
                          (precedes ?s1 ?s2)
                          (=> (ist ?s1 "(constrains ?mc1 ?ste)")
                              (ist ?s2 "(constrains ?mc2 ?ste)"))))))
```

Nesting and Sequencing of Phases

A surgical procedure is a part of a *healthcare activity* (eg, *control* or *prevent* a disease, perform a precise diagnosis). Surgeons manipulate *structures* (body parts, substances, devices) to fix damaged *functions* (including aesthetical function) or induce *functional reactions* from organism. Finally, surgeons exploit means instrumental to the above changes (ie. devices and chemical or physical agents) to perform *technical* actions.
Most deeds therefore consist in *changes* to a structure (eg, adding, removing or transforming it) to achieve a functional effect in the same or another structure (eg, *elimination* of a pathological function, to avoid further consequences in the organism).

ON8.5 provides *mereological* (phase) and *actantial* (cause or goal) relations to express the dependencies among various kinds of action: a *technical action* is a constitutive phase (as well as a cause) of a structural action. A *structural action* in turn is a phase of a *functional action*, that is a constitutive phase of (as well as it has as goal) a *healthcare activity* .
These points of view correspond to classes of criteria to organize deeds (§ 3.2).

Moreover, surgical telic events can be considered as sequences of constitutive phases. For example, *remove* and *insert* are constitutive phases of *replacement*, while *remove* from a *donor* is an additional constitutive phase of *transplant.* Analogoulsy, *sampling* could be intended as *disconnecting* a portion and *remove* it.
We modelled this dependency by introducing the "surgical act", as explained in § 3.3.

3.2. Mereological and Actantial Dependencies Among Deeds

Intuitive considerations on points of view correspond to constraints in table 2, and they lead to a set of criteria to describe and organize deeds.

Point of View Regarding Structures and their Context

The "structural" point of view considers situations in the time span of a surgical action, and focuses on actual changes in properties of the *structure* which embodies the action ('direct object' in CEN), or on its regional *context*; it corresponds to the *ist* metalinguistic constraint on properties of structures, ranging over a context (a *situation*) and a *meta-concept* containing a logical expression about the situation.

Table 3 presents some informal interpretation hints (the preferred interface to experts) to organize surgical telic events in relation to the *structuring* concepts that change from a situation to another. Such structuring concepts are organized in ON8.5 as: *mereological* concepts (part-whole relations); *topological* concepts (connexity relations); *morphological* concepts (qualitative and quantitative relations on matter).

Our model then distinguishes surgical telic events focalizing primarily to:

- *mereological* properties (ie to regional context) of the structure involved;
- *morphological* properties of the structure involved;
- *topological* properties of the structure involved, eg. regarding its connections to other structures, or its topological *genus* (various kinds of holes).

Further criteria (not in table 3) depend on specialization of those structuring concepts:

- kind of structure involved (body part, device or substance);
- physical state of the structure (eg. fluid, solid).
- for quantitative properties, "increase" vs "decrease" in number or size;
- for extended topological properties, weak or strong connexity.

A surgical telic event may encompass various constitutive actions which change different properties; eg, *sampling* amounts to *disconnect* portions or non-essential elements of a biologic structure and to *remove* them from the organism (see § 3.3).

table 3. Properties of structures changed by a structural point of view (with examples and notes on the right)

shape	reconstruct, reduce a fracture
size	dilate, lengthen
physical state	vaporize, melt
hygienical state	sterilize
having holes	(temporary) patency/closure, clamp (vessel), stomy
connexity of parts	split, fragment, sampling (portions), fix (fracture)
connection to other structures	anastomosis
being a part of patient	remove, drain, insert (temporarily), harvest
being a part of region	transfer
having anchors	fixation, -pexy, release
position of anchors	advance (a tendon)

Point of View Related to Functional Outcome of the Procedure

The "functional" point of view considers the situation after the surgical procedure, and focuses on functional changes *to be achieved* by the "structural action" above; it corresponds to possible *ist* metalinguistic constraints on biologic functions (in case of complex, encapsulated goals). In table 4 we present the criteria to organize actions in relation to the functional outcome of the procedure.

Additional criteria to further organize deeds from a functional point of view (not in table 4) consider the degree of restoration or loss of performance, referred to:

- a structure (either a body part, a body system, or the whole organism), and
- the kind of reference situation (ie, a pathological or normal situation).

table 4. Potential functional changes of a structure (with examples and notes on the right)

loose functional role	isolate functionally
adapt to other function	by transfer or morphological changes (make a reservior)
restore original function	(totally, partially); functional repair
assist existing function	by installing prosthesis
no relevant change in function	for acquisition of information or sampling

Point of View Related to the Technical Aspect of the Procedure

A third point of view (table 5) regards the "technical" way to perform an operation (ie, how the surgical telic event is actually performed); it corresponds to the *is-instrumental-for* constraint in table 2, ranging over the telic event and either a *chemical agent*, *a physical agent* or a *device*. Note that sometimes the use of a device determines particular structural surgical actions: eg, "to clamp a vessel" implies not only the use of the instrument, but also *compression* and *closure* of lumen (see §4.2).

table 5. Means exploited in the instrumental point of view; the effect is not explicit in the deed (examples of deeds are on the right)

chemical agents	alcoholization
physical agents	warming, compression
devices	cut, drill, clamp, inject

3.3. Surgical Acts and Sequences of Constitutive Acts

Further studies on surgical actions have required an understanding of the telic events which have the role of *constitutive acts* within a surgical telic event, called *surgical acts* in our model. Some of such acts as *move*, *separate*, *destroy*, etc. have been defined: *move* definition is shown in table 6. The ontological definition of *surgical act* is made in order to impose less constraints as possible: for instance, what embodies a *move* is a generic *structure*, since either *body parts*, or *substances*, or *artifacts*, or

Table 6. Formal definition of the surgical act "move" as stipulated within the ontology on surgical procedures

```
(define-class move (?m)
"a move as a surgical act is a telic event embodied in a structure which is in one
region of an organism. Such an event has the goal of having that structure in a
different region of that (or another) organism. A moving entails a moving from a
position and a moving to another position, temporally ordered: this is intended here
as old and new situations."
  :def (and (*surgical-act ?m)
            (=> (*surgical-act ?m)
                (exists (?p ?r1 ?r2 ?s1 ?s2 ?org1 ?org2)
                        (and (structure ?p) (region ?r1) (region ?r2)
                             (situation ?s1) (situation ?s2)
                             (organism ?org1) (organism ?org2)
                             (is-part-of ?r1 ?org1)
                             (or (is-part-of ?r2 ?org1)
                                 (is-part-of ?r2 ?org2))
                             (precedes ?s1 ?s2)
                             (=> (ist ?s1 "(and (has-position ?p ?r1)
                                                (embodies ?p ?m))")
                                 (ist ?s2 "(has-position ?p ?r2)")))))))
```

abnormal structures can be moved surgically. Moreover, a *structure* has a generic *position* to a *region*, since a region is meant to be the *contextual around* which is focalized constructively: the region can be the *whole* of the structure, or can *contain* it, or can be even *adjacent to* it, etc.
On the other hand, when a surgical telic event is defined through some of its surgical acts, more specific items are to be represented (ie., specific type restrictions are made).
The final goal of having surgical acts analyzed is to define an algebra of surgical procedures, that could be integrated in a more general algebra of procedures.

4. Discussion

Discussion is organized in 2 parts. First we explain the rationale of our methodology. Second, we see how points of view influence analysis and systematization, and how the basic properties of a surgical procedure could be better understood.

4.1. On Ontological Analysis and Modeling Methodologies

Support of cooperative modelling requires a methodology for early discovery of potential sources of conflicts among modellers, early reconciliation, minimization of interactions by focusing on anticipated issues, etc.
It is hard to integrate cooperative efforts —not only in GALEN-IN-USE, but also among CEN standards on various subject fields and among CEN standards and other initiatives— without a unique, ontologically based framework.
Timely discovering of uniform (stable) principles is crucial to establish guidelines and to perform integration among independently developed fragments of models.

Issues on integration. Ontological analysis is a craft; but this does not prevent to state reasonable principles and guidelines for a rigorous and intersubjectively controllable work. ONIONS guides the knowledge engineer to answer the following main issues:

1 *corpus formation*, ie, strategies for finding valuable sources, checking for their terminological organization and their definitions (if any), possibly sampling or chunking them to the needed extent, etc.;
2 *rearrangement of concepts extracted from terminologies* (dictionaries, taxonomies, nomenclatures, semantic networks, formal languages) within possible hierarchies and through informal discussions. The outcome should include *explicit criteria* used for the various hierarchical rearrangements;
3 *integration of criteria*, according to general and domain theories triggered from literature. Such general theories are accepted to the extent they provide the minimal structure to create a framework for integration of criteria. Minimal structure should include a minimal *top level* as well;
4 *formal modelling*, ie., assignment of concepts resulting from 1, 2, and 3, to some representational primitives (sorts, roles, relations, properties, etc.), syntactically organized in a formal language (predicate logic, Ontolingua, KIF, conceptual graphs, etc.) and with explicit logical semantics. This should account for axiomatic treatment of the ontology;
5 *implementation of the formal ontology*, and its testing with experts.

Ambiguity of NL and precision of the model. Words are our initial experimental material, but we analyze definitions and additional information in order to discover principles as much language independent as possible: we *conceptualize* words.
We considered any word with different entries (eg "reduce" fracture vs "reduce" volume) as two independent concepts to be modelled. But there are subtler cases of context-

dependent shifts on sense; routine mapping from actual words-in-context (eg from medical records) to our model has to be carefully made for each terminological phrase, on the basis of ontologic constraints and not by similarity of wording.

4.2. On the Organization of Surgical Deeds

Our results on surgical deeds provide:

- principles and general issues; they could also be an input for the planned revision of the CEN standard, or for the enhancement of the top-level ontology in GALEN;
- the representation of individual deeds; it could also be validated and integrated in the model of surgical procedures being developed by the GALEN-IN-USE project;
- informal descriptions of plausible points of view for practical use by domain experts (presented in three tables, according to the domain ontology).

As shown in § 3.2, a deed explicitly refers to one or more points of view; but in most cases, specially if embedded in a particular context, a given phrase evokes by default in the mind of surgical specialists a complete healthcare process, and a set of potential transformations between viewpoints. In other words, knowledge on the process from one view puts strong constraints on other views.

Relations between a surgical telic event and the involved structures and processes apparently depend on linguistic *focalization*; eg, "repair femur with 2 pins" focuses on a body part (*femur*) embodying the event, on a surgical act (*repair*) and on a device (*pin*) having the role of instrument (*with*). A different focalization appears when the instrumental word (*with*) is paraphrased so that the implicit "insert 2 pins in femur" explicitly emerges. This last phrase focuses on the device (*pin*) and a different surgical act (*insert*), keeping the body part (*femur*) as a positional reference.

Actually, the two phrases are both partial views of the same complex domain conceptualization which accomplishes a surgical telic event (say: *bone repair*) embodied in a body part (*femur*) through the main phase consisting of a technical act (say: *exploit pins*), let alone other possible phases.

In other words, the *same* intervention can be represented from different points of view, producing different constructs and formally different representations (table 7).

Note that for a specialist, different views are often transformable into each other.

table 7. Dual views of some surgical telic events [cf Rossi Mori96b]

structural action	technical action
repair femur with 2 pins	inserting 2 pins in femur
destroy a nerve by neurolytic fluid	injecting neurolytic fluid
release bowel	lysing peritoneal adhesions
dilatation of artery	perfoming a balloon catheterization
increase temperature of tumor mass	warming blood

Table 3 to 5 were consequences of these considerations (the fourth point of view on healthcare activities is not discussed in this paper). Depending on task, a procedure can be described by a set of criteria according to any of those viewpoints.

This modelling activity could be a spin-off point to actual knowledge acquisition (ie. connections between multi-functional domain ontologies and problem-solving methods [cf. Musen92]).

An independent axis of description is obtained by the introduction of surgical acts (§ 3.3), that allow to express a deed by a sequence of more elementary acts, on the same or different structures.

5. Conclusions

Cooperative modelling adds severe problems of coherence to the difficult task of formal modelling. Integration of independent efforts is practically impossible without sharing a unique goal: a stable ontological foundation.

CEN initiatives on medical terminologies produce a first approximation of criteria to organize concepts within particular subject fields in healthcare; but a fixed schema cannot satisfy the raising needs of integration of multiple purposes and views.
Nevertheless, we showed that their results on surgical procedures can be the starting point to perform a subsequent ontological analysis, to:
1. discover and make explicit deep ontological principles;
2. interpret the principles within a solid general framework (eg, our model ON8.5).

Our methodology uses coding systems as sources for well-organized knowledge, in order to assure coverage and an intersubjective approach. We also used authoritative definitions to anchor our compositional analysis to a recognized basis.
In this paper we outlined a set of criteria for surgical experts, suitable to let them express different points of view; the various perspectives lead to different subsets of primitives and multiple organizations among them.

Our results can be used by the European Standardization Body to revise the standard on surgical procedures, as well as by the GALEN-IN-USE project, that is populating a formal model on surgical procedures. Finally, by suitable application of our criteria, end-users can build specialized hierarchies for their particular tasks.
Our approach can be generalized to analyze and integrate semi-formal models ("*categorial structures*" in [CEN96]) developed by independent initiatives. Their results can fit into an incremental mosaic, and endorsement by CEN could assure adequate exploitation of the model as a whole, within terminological systems for advanced information systems in healthcare [Rossi Mori96a, Rossi Mori95].

Acknowledgements Work partially supported by the Committee on Information Sciences of CNR, under the Program on "Strumenti Ontologici e Linguistici per la Modellizzazione Concettuale" (Ontological and Linguistic Tools for Conceptual Modelling), 1994-1996.
Work also partially supported by European Union, under the IV Framework Program (Project GALEN-IN-USE); actual cooperative modelling of rubrics from coding systems on surgical procedures, including discussions with other European Centers, was a stimulating environment for develoment of ideas presented in this paper.

References

Averill RA, Mullin RL, Steinbeck BA, Goldfield NI, Grant T. The development of the ICD-10 Procedure Coding System (ICD-10-PCS), 1995. available from: 3M Health Information Systems, 100 Barnes Road, Wallingford CT 06492.

Bernauer J. Merged list of deeds from GRAIL and German version of ICPM. GALEN-IN-USE, Internal Document, 1996

CEN ENV 1828:1995. Health care informatics — Structure for classification and coding of surgical procedures. Brussels: CEN, 1995

CEN ENV 12264:1996. Medical Informatics — Categorial structure of systems of concepts — Model for representation of semantics. Brussels: CEN, 1996

Dorland's Illustrated Medical Dictionary 28th ed, WB Saunders Co., Philadelphia 1994

Falasconi S Stefanelli M. A Library of Medical Ontologies. in N Mars (ed), *Workshop on Comparison of Implemented Ontologies, ECAI 94*, 1994

GALEN and GALEN-IN-USE documentation 1992-96, available from the main contractor A Rector, Medical Informatics Group, Dept. Comp Sc, Univ. Manchester, Manchester M13 9 PL, UK (e-mail galen@cs.ac.man.uk; home page http://www.cs.man.ac.uk/mig/galen)

Gangemi A, Steve G, Rossi Mori A. Cognitive Design for Sharing Medical Knowledge Models. in Kaihara (ed.), *Proceedings of MEDINFO-95*, 1995

Gangemi A, Steve G, Giacomelli F. ONIONS: An Ontological Methodology for Taxonomic Knowledge Integration. In van der Vet (ed.) *Proc Workshop on Ontological Engineering, ECAI96*, 1996

Gruber T. A Translation Approach to Portable Ontology Specifications. *Knowledge Acquisition* 1993; 5:188-220

Guarino N, Carrara M, and Giaretta P. An Ontology of Meta-Level Categories. In J Doyle, E Sandewall and P Torasso (eds.), *Principles of Knowledge Representation and Reasoning: Proc. of the Fourth International Conference (KR94)*. Kaufmann, San Mateo, 1994.

Guarino N Ontologies and Knowledge Bases: Towards a Terminological Clarification- in *Proc 2nd Int'l Conf on Building and Sharing Very Large-Scale Knowledge Bases* , 1995

HCFA: Health Care Financing Administration, U.S. Department of Health and Human Services. *International Classification of Diseases, 9th rev. Clinical Modifications (ICD-9-CM), vol. 3 - Procedures*, DHHS-HCFA, 1988

Kolozig Ch, Thurmayr R, Diekmann F, Raskop AM (eds). Internationale Klassifikation der Prozeduren in der Medizin, Blackwell, Berlin 1994

McCarthy J, Buvac S. Formalizing Context. Stanford Tech Note STAN-CS-TN-94-13, 1994

Musen M. Dimensions of Knowledge Sharing and Reuse*Comp Biom Res* 1992;25:435-67

Oxford. The Concise Oxford Dictionary of Current English, Clarendon Press Oxford, 1995

Rossi Mori A, Galeazzi E, Agnello P, Steve G, *Terminological modelling in CEN/TC251/ WG2 and GALEN: the example of surgical procedures.* in Proc. AMICE 95 "Strategic alliances between patient documentation and medical informatics", Amsterdam, 1995

Rossi Mori A. Coding systems and controlled vocabularies for hospital information systems. *Int J Biom Comp* 1995;39:93-8

Rossi Mori A. Towards a new generation of terminologies and coding systems. in J Brender et al. (eds), Medical Informatics Europe '96, IOS Press, Amsterdam 1996, 208-12

Rossi Mori A, Galeazzi E, Consorti F, An Ontological Perspective on Surgical Procedures. JAMIA 1996; symp suppl: 115-9 (1996b)

Rothwell DJ, Coté RA, Brochu L (eds), *SNOMED International*, Northfield, IL: College of American Pathologists, 1993, 3rd ed.

Schreiber AT, Wielinga B, Breuker JA (eds.). KADS: A Principled Approach to Knowledge-Based Systems Development. Academic press, London 1992

Shadbolt N, Motta E, Rouge A. Constructing Knowledge Based Systems. IEEE Software, 10, 6, 1993

Shapiro SC, Rapaport WJ. The SNePS Family. In F Lehmann (ed.): Semantic Networks in Artificial Intelligence, Pergamon, Oxford, 1992: 243-275.

Stedman's Medical Dictionary, 26th edition, Williams & Wilkins, Baltimore 1995

Steve G, Gangemi A. Modelling a Sharable Medical Concept System: Ontological Foundation in GALEN. in Artificial Intelligence in Medicine Europe, AIME95

Steve G, Gangemi A, Rossi Mori A. Knowledge Integration of Medical terminological Sources: An Ontologic mediation. In S.Ali(ed.): *Proc FLAIRS 96 Track on Information Interchange*, 1996a

Steve G, Gangemi A. Ontological Commitment in the ONIONS Methodology. in B Gaines, G van Heijst (eds), *Proc. of KAW (Knowledge Acquisition Workshop) 96*, 1996b

Uschold M, King M. Towards a Methodology for Building Ontologies. IJCAI95 Workshop on Basic Ontological Issues in Knowledge Sharing, 1995

van Heijst G, Schreiber ATh, Wielinga BG. Using Explicit Ontologies in KBS Development. *International Journal of Human-Computer Studies*, to appear, 1997

Wiley: International Dictionary of Medicine and Biology, 3 voll., Churchill Livingstone, New York, 1986

Wordnet, available from http://www.cogsci.princeton.edu/~wn/