Having our cake and eating it too: How the GALEN Intermediate Representation reconciles internal complexity with users’ requirements for appropriateness and simplicity

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Clinical terminologies are complex objects, getting more complex as the requirements on them grow, and as more complex technologies are used in their construction. But to the clinical end-user, functionality and utility is important, not inherent complexity — the simpler a clinical terminology can be for the end-user, the better.

To reconcile these contradictory requirements, the GALEN Programme has developed an Intermediate Representation that allows the OpenGALEN Clinical Terminology to retain a high degree of internal complexity, whilst allowing it to be efficiently maintained, and easily used. This paper describes the elements of the Intermediate Representation, how it works, and some experience of its use.

INTRODUCTION

Clinical terminologies have contradictory requirements. On the one hand, they need to be complex to represent medical concepts. On the other, users require simplicity. The complexity of clinical terminologies has several axis:
1) The scale of medicine forces them to be large.
2) As the requirements on clinical terminologies grow, so their complexity grows.
3) New levels of detail and technologies are being brought to bear on the issue. For example, NHS CTV3 includes semantic descriptions of the structure of terms within it¹. SNOMED RT takes this a step further and uses an external description logic classifier to help organise its structure². The GALEN Programme³, ⁴ also uses description logics, and is, by necessity, complex; the OpenGALEN Clinical Terminology⁵ is designed to support many applications. It can be delivered as an active resource within a GALEN Terminology Server⁶, as well as forming part of the support infrastructure for the maintenance and delivery of other coding and classification systems⁷.

Description logics are complex
The experience of the GALEN Programme has been that the use of description logics brings its own problems. The level of detail and structure that description logics allow - and which are needed if the clinical terminology is to live up to its new expectations - makes authoring and maintenance more difficult. See for example Rogers and Rector⁸, which illustrates the range of partonomic relationships now required. Building and maintaining a clinical terminology in such an environment requires more than traditional clinical skills.

Users require simplicity
A successful clinical terminology must disappear into the underlying infrastructure; the end-user simply wants better tools with which to do a better job. This applies equally whether the end-user is a physician entering documentation into an electronic patient record, or producing a clinical terminology.

The GALEN Intermediate Representation
To reconcile these contradictory requirements, we have developed a layer of abstraction between clinical end-users and the underlying technology: the GALEN Intermediate Representation (GALEN IR). This acts as a high-level language for GRAIL, the description logic used in the OpenGALEN Clinical Terminology⁹. We have previously described motivation for the GALEN IR in detail¹⁰. This paper describes for the first time the elements of the GALEN IR, how it works, and experiences of its use.

REQUIREMENTS ON THE GALEN IR
The GALEN IR has been designed to satisfy the following requirements.
1) Allow clinicians to use clinical knowledge to build the terminology without specialised knowledge of description logics or the style of the underlying model. This overcomes a knowledge acquisition bottleneck and optimises use of clinical knowledge.
2) Separation of clinical knowledge authoring from detailed internal implementation choices.
3) We must be able to build efficient software to translate between the GALEN IR and GRAIL.
4) Definition of simpler interfaces to the OpenGALEN Clinical Terminology for other systems (see for example Webber et al¹¹).
5) We must be able to build development environments to support its use.
6) Support for providing guidance for end-users. There are also a number of requirements specific to the GRAIL target language:
   • The use of words closer to day-to-day clinical language than GRAIL knowledge-names.
   • The ability to use different natural languages
   • The use of a small number of semantic links, instead of the large number of GRAIL attributes.
   • The use of a simple recursive structure rather than the complex, multi-attribute-concept chains that are necessary in GRAIL.
   • The ability to say the same thing in different ways, allowing for local variation in style.

**SATISFYING THE REQUIREMENTS**

An example
We illustrate the GALEN IR using the surgical procedure that excises a lobe of the lung. The ‘dissection’, or semantic description of this concept in GALEN IR, is shown in Figure 1.

```
RUBRIC "excision of lobe of lung"
MAIN excising
ACTS_ON lobe
IS_PART_OF lung
```

Figure 1: an example dissection

Words in lowercase, designed to be familiar to any clinician, are known as ‘descriptors’. Words in uppercase are ‘links’, and users of the GALEN IR must be able to appropriately use a small number of them. Indentation represents recursive structure: the lobe of the lung is what is excised. Figure 2 shows the underlying GRAIL representation for the concept.

```
(SurgicalDeed which
isMainlyCharacterisedBy (performance whichG
isEnactmentOf (Excising which
playsClinicalRole SurgicalRole) which
actsSpecificallyOn (Lobe which
isSpecificSolidDivisionOf Lung))).
```

Figure 2: GRAIL expression representing ‘excision of lobe of lung’

**Overview of the GALEN IR**
The GALEN IR consists of a number of components:
   • A controlled vocabulary of descriptors and links that are mapped to elements of the OpenGALEN Clinical Terminology, and are sufficient so as to be able to describe clinical concepts.
   • Tools and environments to build and maintain that resource.
   • A specification of how structures containing elements are automatically translated into GRAIL concept expressions;
   • Implementations of that specification. (Two implementations have been illustrated in the GALEN programme).

The overall flow, with all these components, is shown in Figure 3:

![Figure 3: GALEN IR components and interactions](image)

Without the GALEN IR the only entry route to the OpenGALEN Clinical Terminology is for expert users, using GRAIL. With the GALEN IR, an extra entry-point for non-expert users is provided. It becomes possible to build end-user tools (such as the Classification Workbench) requiring less specialised knowledge of the internal description logic.

**DISSECTIONS TO GRAIL**
The translation of dissections to GRAIL makes use of three kinds of knowledge: descriptor mappings, link mappings and structural transformations. It follows the following steps:
   • Rearrangement and transformation
   • Translation of the dissection start point
   • Recursive translation of the dissection body
     • Descriptor to concept mapping
     • Descriptor mapping rules
     • Link to attribute mapping

The translation is described below. Examples of knowledge used in the translation are shown as abstract rules in Figure 4, and referred to throughout the description. The complete translation of the dissection in Figure 1 to the GRAIL in Figure 2 is shown in Figure 5.

**Rearrangement and transformation**
For modelling brevity, a single dissection can represent several similar concepts. These are folded in to a single dissection using various disjunction keywords. Before translation of individual dissections, these are unfolded in to sets of dissections. An example is shown in Figure 4a. Other transformation rules can be applied – for example all of a dissection after a given link can be suppressed (useful for partial compilations), shown in Figure 4b.

**Start point**
Each GRAIL concept starts with a wrapper — in Figure 2, SurgicalDeed. The GALEN IR allows the definition of separate configurations, to which each
different mappings when describing a piece of
used. For example, the descriptor 'bone' may have
the context — in terms of the link — with which it is
provide different descriptor mappings according to
concept. Occasionally it is useful to be able to
Usually, a descriptor maps to a single GRAIL
Descriptor to concept mapping
(a) Dissection expansion rule
MAIN x₁ OR_MAIN x₂ ->
{MAIN x₁, MAIN x₂}
(b) Link suppression rules
If l:S then d₁, l d₂ -> d₁
(c) Adding a start point
MAIN x -> cstart, MAIN x
(d) Descriptor to concept mapping
l? d -> l? c
(e) Specialisation rule
if c:C and l:L
then l c -> l c which a,c,s
(f) Wrapping rule
if c:C and l:L
then l c -> l c which a,c,s
(g) Chains of attributes
l -> which a,c,...
...which a,c,... which a,x
(h) Context-specific link disambiguation
c₁,c₂,c₃ -> c₄ \{A₁,... Aₙ\} c₅
(i) Sanctioning information in link disambiguation
For each possible link to attribute chain mapping
in \{A₁,... Aₙ\}, the first attribute chain is chosen where a sanction exists in the OpenGALEN
terminology for both c₁, a,c₁ and c₃, a,c₃. In the
special case where A₁ = a, c₁, a,c, is checked.

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**Key**

x: dissection body; d: descriptor; l: link; S: set of
suppressed links; l:S link of type S; c: GRAIL
concept; a: GRAIL attribute; c:C concept of type C;
L: set of links defined for a specific rule; a,c,e and c,w
a:w: pairs of defined concepts and attributes used in
specific subsumption and wrapping rules; A: attribute
chain of the form a,c₁,... which a,cₙ-1, a,cₙ

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**Figure 4:** Example abstract rules for GALEN IR to
GRAIL translation

**Descriptor to concept mapping**

Usually, a descriptor maps to a single GRAIL
concept. Occasionally it is useful to be able to
provide different descriptor mappings according to
the context — in terms of the link — with which it is
used. For example, the descriptor ‘bone’ may have
different mappings when describing a piece of
anatomy, or graft material. The general mapping rule
is shown in Figure 4d.

Many descriptor mappings are trivial: for example in
the mapping of the descriptor ‘lobe’ to the GRAIL
concept ‘lobe’. This is true only given that the
language of the descriptor (English) is the same as
that used in the GRAIL authoring.

Some examples are not so trivial, either to cope with
inherent ambiguity in natural language, or to cope
with specifics of the GRAIL description logic. For
example, the term ‘appendix’ is ambiguous, yet
within specific contexts of use is well-understood; so
the ambiguous descriptor ‘appendix’ is mapped to the
more explicit GRAIL concept AppendixVermiformis.

In many cases, descriptors used by authors will be
defined within the GALEN IR. A problem is
encountered when authors add new descriptors with
no mappings. To solve this, authors assign a category
to new descriptors. They are then mapped via this
category to roughly the right part of the
OpenGALEN Clinical Terminology. Further accurate
mapping is then required by GRAIL modellers.

**Descriptor mapping rules**

Additional complexity is handled with **descriptor mapping rules**. For example, the GRAIL expression
representing the ‘deed’ part of a surgical procedure
needs to be ‘surgical excising’ rather than just
‘excising’. Rather than map the descriptor ‘excising’
(and other deeds) to this more complex expression,
we add a **specialisation rule** stating: “if the descriptor
maps to a kind of GenericProcess, and follows one of
a specified set of links, add the criterion ‘which
playsClinicalRole SurgicalRole’”. So the Descriptor
“excising” in Figure 1 is mapped to the concept
“Excising” which is transformed by a specialisation
rule to “Excising which playsClinicalRole
SurgicalRole”. This is shown in Figure 4e.

We can also add **wrapping rules**. For example,
dissections may use a descriptor that maps to an
active drug ingredient as shorthand for a drug. So the
descriptor ‘Atenolol’ is read as ‘drug with active
ingredient Atenolol’. The descriptor needs to be
translated to the GRAIL ‘Drug which hasIngredient
Atenolol’. The wrapping rule states: “if the descriptor
maps to a kind of ActiveDrugIngredient, and follows
one of a specified set of links, wrap with ‘Drug which
hasIngredient’”. This is shown in Figure 4f.

Another mapping variant makes the GALEN IR more
powerful. The granularity of descriptors can be
controlled by mapping to other dissections, and
thence to GRAIL, rather to GRAIL directly.

**Link to attribute mapping**

Links map to either a single GRAIL attribute, or to a
‘concept-attribute-concept’ (or more complex) chain.
The general case is shown in Figure 4g. In the figure 1, the link ‘MAIN’ is mapped to the chain

\[ \text{isMainlyCharacterisedBy performance whichG isEnactmentOf} \]

This mechanism is also useful for translating features; for example the link ‘HAS_SEVERITY’ needs to be translated into the GRAIL chain:

\[ \text{hasSeverity Severity which hasAbsoluteState} \]

Each GALEN IR link is potentially translated into one of many GRAIL attributes or chains. This is particularly true of partonomic relationships, where the OpenGALEN Clinical Terminology maintains many different flavours of links, for example to cope with the fact that the relationships between a) the shaft of a femur and the femur, and b) between the femur and the leg, have different meanings.²

To keep matters simple for the users of the GALEN IR, we have just two partonomic links: ‘HAS_PART’ and ‘IS_PART_OF’; this offers a prime example of the mechanism within the GALEN IR for expanding IR links to GRAIL attributes. It is a two-stage process; the first stage requires additional information: context-specific link disambiguation, and the second stage uses sanctioning information already present in the OpenGALEN Clinical Terminology for further disambiguation. This is shown in Figure 4h and 4i.

**Context-specific link disambiguation:** each link may have multiple potential mappings to a candidate set of GRAIL attributes, controlled by the combination of the type of GRAIL concept of the ‘topic’ of (descriptor before) the link and the ‘value’ of (descriptor after) the link. The link mapping rules say that, for the context lobe - IS_PART_OF - lung (Figure 1) the correct translation is by using one of a candidate set of GRAIL attributes including

\[ \text{isSpecificSolidDivisionOf} \]

whereas in another dissection containing skin - IS_PART_OF - leg the correct translation uses one of a candidate set that includes the GRAIL attribute

\[ \text{isSurfaceDivisionOf} \]

The authoring of these rules is kept manageable by exploiting the use of the classification structure in the OpenGALEN Clinical Terminology — the rules are described at as general a level as possible.

**Sanctioning information:** another axis of disambiguation from the candidate sets as described in the previous section, is provided by the sanctions present in the OpenGALEN Clinical Terminology: only the GRAIL attribute within a candidate set that is suitably sanctioned will be used as the final choice in the translation of the original IR link.

In the examples, links are translated into ‘defining’ properties (definitional features) of the resulting GRAIL. In some circumstances, for example when describing the properties of concepts (such as the indications for a drug) link mappings can be annotated with a non-definitional GRAIL property.

```
(SurgicalDeed
   which
      isMainlyCharacterisedBy
         performance whichG
            isEnactmentOf
    )

excising
   (subsumption rule)

ACTS_ON
   (link mapping)

lobe
   (descriptor mapping)

IS_PART_OF
   (context disambiguation)

lung
   (descriptor mapping)
```

**Figure 5:** A complete translation (dissection indentation not taken in to account)

**EXPERIENCES OF USING THE GALEN IR**

The GALEN IR has been used in the GALEN-IN-USE¹¹ project, and to build a drug ontology for the Prodigy project¹².

Within the Prodigy drug ontology project, the GALEN IR has been used for the rapid modelling of large numbers of concepts by a small number of modellers. It has been most useful for initial knowledge capture of drug information, especially the semi-automated capture of knowledge from semi-structured sources. It has proved useful for adding codes to concepts, providing external references to concepts, and simple compositional modelling. Attempts have also been made to use the GALEN IR as a complete high level language for knowledge authoring, but this has proved unrealistic: the simplicity of the GALEN IR means that it has sacrificed the full expressiveness of GRAIL.

In GALEN-IN-USE, approximately 50 people were trained in nine centres. The usual training period was a three day workshop plus follow-up support. The rate of dissection production varied between centres and the complexity of the rubrics being dissected, but averaged around 50 rubrics per person-day including quality assurance.

Informal evaluation by the Dutch GALEN-IN-USE partners suggests that the effort required to revise their surgical procedure was significantly reduced by use of the GALEN IR, as compared to conventional means. Even though the effort included a significant ‘front loading’ of initial dissections which would be re-used in future revisions, technical effort was
reduced from over five person months to 2.5 person months. Despite this reduction, the number of issues raised and revisions made was increased more than five-fold. Most importantly, the total effort by experts in committees was reduced from 60 person days to 5 person days. These results require replication, but are consistent with the experience of the French partners in developing their new national classification of procedures. This suggests that the GALEN IR can produce a dramatic improvement in productivity in maintaining and revising classifications.

It was anticipated that translation of some dissections to GRAIL might require manual disambiguation. This has so far proved unnecessary: all translation has been fully automatic. The transformation rules plus the constraints provided by GRAIL’s sanctioning mechanisms have so far proved adequate. The descriptor category mechanism, added to cope with unseen descriptors, usually allows reasonable classification for initial checking, but requires accurate GRAIL modelling before classification is fully correct. Within surgery such central modelling effort has averaged on the order of 10% of the effort to produce and quality assure the dissections initially.

**CONCLUSION**

We have discussed a way to overcome the internal complexity of the OpenGALEN Clinical Terminology in order to make it easy and efficient to build and maintain. Revisiting the requirements, the use of the GALEN IR has enabled us to:

1. Build tools so that clinicians can contribute with minimal training and additional knowledge;
2. Experiment with different ways of translating dissections;
3. Provide a target representation for other systems;
4. Build a development environment to support its use;
5. Build tools that contain constraints to guide end-users in their use of the GALEN IR;
6. Build tools that contain constraints to guide end-users in their use of the GALEN IR.

We believe that the OpenGALEN Clinical Terminology — and the GRAIL description logic in which it is written — is complex because it needs to be — not because it is over-engineered. To be usable, that complexity has to be managed. We have used a strategy analogous to that found in other fields: create a level of abstraction between the end-user and internal complexity. The complexity is not removed; it is isolated so that it can be managed.

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**REFERENCES**