ON DEFINITIONAL PROCESSES IN KNOWLEDGE RECONSTRUCTION SYSTEMS

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ABSTRACT

Defining concepts is a fundamental process of modelling a certain domain of knowledge. Current knowledge representation languages, even those said to support terminological adequacy, still suffer from severe epistemological deficiencies. Especially the procedures for defining subconcepts are shown to be inadequate. A basic analysis of primitive concept formation processes yields some general requirements for the definitional part of a knowledge reconstruction device comprising the possibility to model system aggregation, role, collection, and membership abstractions.

1. Introduction

Defining concepts covering a certain domain usually yields a hierarchical taxonomy and a corresponding *terminology*. This has been the main import of semantic networks, frame languages, and even semantic data models [viz. Hammer/McLeod 1981]. Especially with the first kind of representation schemes, problems arise if the necessary distinctions are not observed. I will look at frame oriented languages, in particular those claimed to support "*terminological adequacy*" in knowledge engineering. An example taken from Brachman et al. [1983] will illustrate some aspects of the problem. They define the concept of "*family*" as:

> "a social structure with, among other things, a male parent who is a man, a female parent who is a woman, and some number of children, all persons"

corresponding to the KRYPTON expression:

```
(PrimGeneric
 (ConjGeneric
  (NRGeneric
   (VRGeneric social-structure male-parent man)
   male-parent 1 1)
  (NRGeneric
   (VRGeneric social-structure female-parent woman)
   female-parent 1 1)
  (VRGeneric social-structure child person)))
```

The inadequacy of this view is rather obvious: it suggests that an arbitrary "social structure" may have an arbitrary number of relation (that is the meaning of "role" [viz. Brachman/Schmolze 1985]) instances connecting it, a.o. to "male-parents", and "family" is a subconcept that happens to have just one. Thus, "family" appears to be an *atomic entity* that participates in the relationships to entities of type "man", "woman", and "person" called "male-parent", "female-parent", and "child", respectively. In my understanding, however, "family" is a *system concept*, i.e. in general there is a set of interrelated entities which make up a new *complex entity*, the system in which they play a certain *role*.

In the sequel, I will elaborate on the deficiencies concerning some aspects of

- classification/instantiation
- attribution
- generalization/specialization
- system-aggregation (complexion/role)
- set-aggregation (collection/enumeration)

and specify some requirements to be met by a definitional component of a knowledge reconstruction tool.

2. Attribution and the generalization/specialization hierarchy

Specialization of (sub)concepts is a quite debatable issue. There are three or four main methods for defining subconcepts in use:

(1) conjunction of superconcepts
(2) adding of attributes ("slots", "rolesets" etc.)
(3) restricting the values of attributes
(4) restricting the attribute ("role differentiation")

I suggest that only (3) is a useful method for *defining* subconcepts. (1) suffers from the deficiency that there is *no way to decide upon the disjointness* of subconcepts sharing the same superconcept [Schefe 1985].

There are languages providing with some repairs, for example the "decomposition" concept in KRYPTON (KL-ONE has none),

a poor one, however. (2) leads to similar problems. In KRL [Bobrow/Winograd 1977], the subconcept "motor-vehicle" could be given as:

```
motor-vehicle UNIT SPECIALIZATION
   [<SELF (a vehicle)>
    <motor (XOR combustion steam electro)>]
```

As a consequence, it is undecidable (in general it should be semi-decidable):

(a) whether a sibling concept, e.g. "muscle-driven-vehicle" with a slot "instrument" (pedals, oars etc.), is disjoint from "motor-vehicle", and, hence:

(b) whether "motor-vehicle" can have an "instrument" or not, and whether "muscle-driven-vehicle" can have a "motor" or not.

This has also been stated by Hußmann [1984], but has been overlooked by Hayes and Hendrix [Hayes/Hendrix 1980].

An adequate specialization can only be achieved by method (3). Using predicate calculus, the above example becomes:

$$\text{motor-vehicle}(x) ::= \text{vehicle}(x) \wedge \text{propelling-force}(x) = \text{motor}$$

$$\text{muscle-driven-vehicle}(x) ::= \text{vehicle}(x) \wedge \text{propelling-force}(x) = \text{muscle}$$

A category such as "propelling-force" applying to all instances of the superconcept is restricted in some way yielding a new subconcept. By this method of *taxonomic subcategorization* it will be (semi-)decidable that both concepts defined above are mutually exclusive, and exhaustive, depending on whether the "*values*" of "propelling-force" are exhausted or not.

Subcategorization is closely related to *attribution*. The latter raises a question mostly ignored in the literature:

> Is the value of an attribute something *ascribed* to the object, *part* of the object, or even an *object* in its own right (e.g. "motor" in the above example)?

I hold the first opinion. Attributes refer to a *scale*, a set of *values* representing *criteria of observation* (be it real or formal). A typical example is:

$$\text{height}(\text{John}) = 180\text{cm}$$

"180cm" is a value pertaining to a scale of height, an *interval scale*. Beyond this, there are *ordinal* and *nominal* scales. All scales are construed by comparing the object in question with one or more base objects. Thus, in the above example, "motor" is a value of a nominal scale, i.e. it does not represent a part or thing in its own right.

This fundamental issue is obscured in representation languages such as KL-ONE, as "attributes" and "values" are not distinguished from "roles" in "systems", or "relations" to other "entities".

Method (4), "role differentiation" as included in KL-ONE, is not a basic method of taxonomic specialization (see below 3.2).

3. System-aggregation, role and collection concepts

In simple predicate logic and in most AI "representation languages", a universe of discourse is assumed to contain only atomic individuals. A set of interrelated entities, however, must be modelled as a new *complex entity*. To account for this epistemological process I call *system aggregation*, extending the predicate logic by simple aggregates otherwise called tuples will suffice. The "family" example then reads:

$$\text{family}(x) ::= \exists\, u\, v\, w:\ x = \langle u,v,w\rangle \wedge \text{family-rel}(u,v,w)$$

$$\text{family-rel}(u,v,w) ::= \text{man}(u) \wedge \text{father-of}(u,w) \wedge \ldots \wedge \text{children}(w) \wedge \ldots \wedge \text{married}(u,v) \wedge \ldots$$

or by extending KRYPTON:

```
(SystemGeneric family-rel
    father: man
    mother: woman
    children: set-of-persons)
```

The "family-rel" may be as complex as necessary for a certain purpose. The "parts" of the system can now be adressed as genuine roles in a system (not as relationships or attributes). Role concepts become definable in there own right:

$$\text{father}(x) ::= \exists\, u{:}\ \text{family}(u) \wedge u = \langle x,y,z\rangle$$

or in KRYPTONic style:

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(RoleGeneric family father)
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Within a general definitional capability, this extension is a necessary one to define genuine role concepts. The "role sets" of KL-ONE do not pertain, because they mix up attribution and relationships, resulting, e.g. in the amazing "number restriction" for attribute values (on a scale, there can be only one value).

As system aggregation allows for viewing a set of interrelated entities as a new entity, further specialization becomes feasible. However, now it comes in different flavors, namely by way of (1) attribute value restriction, and (2) role filler restriction, e.g.

(1) "A poor family is a family with income < 1000"
(2) "A royal family is a family where the father is a king or the mother is a queen"

The latter example uses the role concepts "king" and "queen" (where the system is "empire") to restrict the filler of the father or mother role in "family".

Subcategorization of role concepts also is at least two-fold:

(a) attribute value or role filler restriction
(b) role differentiation

The first pertains to the entity as a role filler, e.g.

tall-father (x) ::= father (x) ∧ height (x) = tall

This specialization corresponding to a *subrelation* does not necessarily imply a "role differentiation", as Brachman et al. [op. cit.] appear to have in mind. It is a subcategorization pertaining to an entity as a filler, not to the role itself. A *subrole* should be differentiated from its superrole by some function or relation in the system, not by an arbitrary attribute or component restriction, say:

"A crown prince is a subrole of a child in a royal family with inheritance claim where sex = male"

crown-prince ::=
∃ u: royal-family (u) ∧ u = <y,z,w> ∧ x ∈ w ∧
sex (x) = male ∧ inheritance-claim (x,y)

A system may be viewed simply as a collection, thus abstracting from the specific relationships, and an entity may be viewed simply as a member of a system, thus abstracting from its specific role:

family-collection (x) ::=
∃ u v w: x = {u,v} ∪ w ∧ family-rel (u,v,w)

family-member (x) ::= ∃ u: family (u) ∧ x ∈ u

We have to extend predicate logic by set-construction and membership (another conservative extension). The difficulty with the above example is that all subsystems, "children" in this case, have to be collected together. Otherwise, a more complex model of the family would be required, e.g. by modelling a variant number of child-subroles.

4. Analytic and synthetic knowledge

For every simple concept, there is a set (conjunction) of value-restrictions that uniquely determine its position in a definitional lattice. This knowledge is, of course, purely *analytic*. It provides with a certain set of propositions pertaining to a "possible" instance of the concept in question.

We have to make the necessary distinction of *analytic* and *synthetic* knowledge. Clearly, that the lack of a certain part or role results In the malfunction of the system as a whole. is synthetic knowledge. The concept of "a chair with two legs" could be derived from the concept of a chair by role restriction. However, whether this makes sense can be doubted. Hence, a definitional component could be restricted by an *assertinal* one comprising the *constraint,* say:

"A chair must have at least three legs"

thus preventing a knowledge engineer to conceive of "impossible concepts". An "elephant with three legs" or a "truck with two wheels" Is not a concept derived by simple number restriction, but, based on a *description of* a *possible contingent state of a system,* a *new concept dealing with a possible malfunction* of a system.

Analytic and synthetic knowledge, though tightly intertwined, should be kept separatly requiring different modes of reasoning, deduction and (probabilistic) abduction, respectively. To model the correct deductions, i.e. to provide with epistemologlcaHy adequate representations of knowledge, a semantics is required richer than the slot-and -filler -restriction scheme can account for.

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