Knowledge Representation & Reasoning

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From sentences to objects

As we saw with frames, it useful to shift the focus away from the true *sentences* of an application towards the categories of *objects* in the application and their properties.

In frame systems, this was done *procedurally,* and we concentrated on hierarchies of frames as a way of organizing collections of procedures.

In this section, we look at the categories of objects themselves:

- objects are members of multiple categories

  e.g. a doctor, a wife, a mother of two

- categories of objects can be more or less specific than others

  e.g. a doctor, a professional, a surgeon

- categories of objects can have parts, sometimes in multiples

  e.g. books have titles, tables have legs

- the relation among the parts of an object can be critical in its being a member of a category

  e.g. a stack vs. a pile of bricks

Noun phrases

In FOL, all categories and properties of objects are represented by atomic predicates.

- In some cases, these correspond to simple *nouns* in English such as Person or City.
- In other cases, the predicates seem to be more like *noun phrases* such as MarriedPerson or CanadianCity or AnimalWithFourLegs.

Intuitively, these predicates have an internal structure and connections to other predicates.

e.g. A married person must be a person.

These connections hold by *definition* (by virtue of what the predicates themselves mean), not by virtue of the facts we believe about the world.

In FOL, there is no way to break apart a predicate to see how it is formed from other predicates.

Here we will examine a logic that allows us to have both atomic and non-atomic predicates: a description logic

Concepts, roles, constants

In a description logic, there are sentences that will be true or false (as in FOL).

In addition, there are three sorts of expressions that act like nouns and noun phrases in English:

- concepts are like category nouns — Dog, Teenager, GraduateStudent
- roles are like relational nouns — :Age, :Parent, :AreaOfStudy
- constants are like proper nouns — johnSmith, chair128

These correspond to unary predicates, binary predicates and constants (respectively) in FOL.

See also: generic frames, slots, and individual frames.
However: roles can have multiple fillers.

However, unlike in FOL, concepts need not be atomic and can have semantic relationships to each other.

roles will remain atomic (for now)

The symbols of DL

Three types of non-logical symbols:

- atomic concepts:

  Dog, Teenager, GraduateStudent

  We include a distinguished concept: Thing

- roles: (all are atomic)

  :Age, :Parent, :AreaOfStudy

- constants:

  johnSmith, chair128

Four types of logical symbols:

- punctuation: [,], (,)
- positive integers: 1, 2, 3, ...
- concept-forming operators: `ALL`, `EXISTS`, `FILLS`, `AND`
- connectives: $\sqsubseteq$, $\doteq$, and $\rightarrow$

The syntax of DL

The set of concepts is the least set satisfying:

- Every atomic concept is a concept.
- If r is a role and d is a concept, then [`ALL` r d] is a concept.
- If r is a role and n is an integer, then [`EXISTS` n r] is a concept.
- If r is a role and c is a constant, then [`FILLS` r c] is a concept.
- If d_1, ..., d_k are concepts, then so is [`AND` d_1, ..., d_k].

Three types of sentences in DL:

- If d and e are concepts, then ($d \sqsubseteq e$) is a sentence.
- if d and e are concepts, then ($d \doteq e$) is a sentence.
- If d is a concept and c is a constant, then ($c \rightarrow d$) is a sentence.

The meaning of concepts

Constants stand for individuals, concepts for sets of individuals, and roles for binary relations.

The meaning of a complex concept is derived from the meaning of its parts the same way a noun phrases is:

- [EXISTS n r] describes those individuals that stand in relation r to at least n other individuals
- [FILLS r c] describes those individuals that stand in the relation r to the individual denoted by c
- [ALL r d] describes those individuals that stand in relation r only to individuals that are described by d
- [AND d_1 ... d_k] describes those individuals that are described by all of the d_i.

For example:

"a company with at least 7 directors, whose managers are all women with PhDs, and whose min salary is $24/hr"

```
[AND  Company
      [EXISTS 7 :Director]
      [ALL :Manager [AND Woman
                         [FILLS :Degree phD]]]
      [FILLS :MinSalary $24.00/hour]]
```

A DL knowledge base

A DL knowledge base is a set of DL sentences serving mainly to

- give names to definitions

  e.g. (FatherOfDaughters $\doteq$
  [AND Male [EXISTS 1 :Child]
  [ALL :Child Female]])

  "A FatherOfDaughters is precisely a male with at least one child and all of whose children are female"

- give names to partial definitions

  e.g. (Dog $\sqsubseteq$ [AND Mammal Pet
  CarnivorousAnimal
  [FILLS :VoiceCall barking]])

  "A dog is among other things a mammal that is a pet and a carnivorous animal whose voice call includes barking"

  gives necessary but not sufficient conditions

- assert properties of individuals

  e.g. (joe $\rightarrow$
  [AND FatherOfDaughters Surgeon]])

  "Joe is a FatherOfDaughters and a Surgeon"

Other types of DL sentences are typically not used in a KB.

e.g. ([AND Rational Animal] $\doteq$ [AND Featherless Biped])