12.2 CATEGORIES AND OBJECTS

The organization of objects into **categories** is a vital part of knowledge representation. Although interaction with the world takes place at the level of individual objects, *much reasoning takes place at the level of categories*. For example, a shopper would normally have the goal of buying a basketball, rather than a particular basketball such as \( BB_9 \). Categories also serve to make predictions about objects once they are classified. One infers the presence of certain objects from perceptual input, infers category membership from the perceived properties of the objects, and then uses category information to make predictions about the objects. For example, from its green and yellow mottled skin, one-foot diameter, ovoid shape, red flesh, black seeds, and presence in the fruit aisle, one can infer that an object is a watermelon; from this, one infers that it would be useful for fruit salad.

There are two choices for representing categories in first-order logic: predicates and objects. That is, we can use the predicate \( Basketball(b) \), or we can **reify** \( \) the category as an object, \( Basketballs \). We could then say \( Member(b, Basketballs) \), which we will abbreviate as \( b \in Basketballs \), to say that \( b \) is a member of the category of basketballs. We say \( Subset(Basketballs, Balls) \), abbreviated as \( Basketballs \subseteq Balls \), to say that \( Basketballs \) is a **subcategory** of \( Balls \). We will use subcategory, subclass, and subset interchangeably._

Categories serve to organize and simplify the knowledge base through **inheritance**. If we say that all instances of the category \( Food \) are edible, and if we assert that \( Fruit \) is a subclass of \( Food \) and \( Apples \) is a subclass of \( Fruit \), then we can infer that every apple is edible. We say that the individual apples **inherit** the property of edibility, in this case from their membership in the \( Food \) category.

**Subcategory relations** organize categories into a **taxonomy**, or **taxonomic hierarchy**. Taxonomies have been used explicitly for centuries in technical fields. The largest such taxonomy organizes about 10 million living and extinct species, many of them beetles, into a single hierarchy; library science has developed a taxonomy of all fields of knowledge, encoded as the Dewey Decimal system; and tax authorities and other government departments have developed extensive taxonomies of occupations and commercial products. Taxonomies are also an important aspect of general commonsense knowledge.

First-order logic makes it easy to state facts about categories, either by relating objects to categories or by quantifying over their members. Here are some types of facts, with examples of each:

- An object is a member of a category.
  \[ BB_9 \in Basketballs \]
- A category is a subclass of another category.
  \[ Basketballs \subseteq Balls \]
- All members of a category have some properties.
  \[ \subseteq Basketballs, Spherical(x) \]

Turning a proposition into an object is called **reification**, from the Latin word *res*, or thing. John McCarthy proposed the term "thingification," but it never caught on.

\(^{2} \) The famous biologist, B. S. Haldane deduced "An inordinate fondness for beetles on the part of the Creator."
Section 12.2. Categories and Objects

• Members of a category can be recognized by some properties.
  \[ \text{Orange}(x) \land \text{Round}(x) \land \text{Diameter}(x) = 9.5'' \land x \in \text{Balls} \quad x \in \text{Basketballs} \]

• A category as a whole has some properties.
  \( \text{Dogs} \in \text{DomesticatedSpecies} \)

Notice that because \( \text{Dogs} \) is a category and is a member of \( \text{DomesticatedSpecies} \), the latter must be a category of categories. Of course, there are exceptions to many of the above rules (punctured basketballs are not spherical); we deal with these exceptions later.

Although subclass and member relations are the most important ones for categories, we also want to be able to state relations between categories that are not subclasses of each other. For example, if we just say that \( \text{Males} \) and \( \text{Females} \) are subclasses of \( \text{Animals} \), then we have not said that a male cannot be a female. We say that two or more categories are disjoint if they have no members in common. And even if we know that males and females are disjoint, we will not know that an animal that is not a male must be a female, unless we say that males and females constitute an exhaustive decomposition of the animals. A disjoint exhaustive decomposition is known as a partition. The following examples illustrate these three concepts:

\[
\text{Disjoint}(\text{Animals}, \text{Vegetables})
\]
\[
\text{ExhaustiveDecomposition}(\{\text{Americans}, \text{Canadians}, \text{Mexicans}\}, \text{NorthAmericans})
\]
\[
\text{Partition}(\text{Males}, \text{Females}, \text{Animals})
\]

(Note that the \( \text{ExhaustiveDecomposition} \) of \( \text{NorthAmericans} \) is not a Partition, because some people have dual citizenship.) The three predicates are defined as follows:

\[
\text{Disjoint}(s) \quad \iff \quad E s \land c2 E s \land c1 \land \text{Intersection}(c1, c2) = \emptyset
\]

\[
\text{Partition}(s, a) \quad \iff \quad \exists i \in \text{Intersection}(s, a) \land i \in c1 \land i \notin c2
\]

Categories can also be defined by providing necessary and sufficient conditions for membership. For example, a bachelor is an unmarried adult male:

\[
x \in \text{Bachelors} \quad \iff \quad x \in \text{Unmarried} \land x \in \text{Adults} \land x \in \text{Males}
\]

As we discuss in the sidebar on natural kinds on page 443, strict logical definitions for categories are neither always possible nor always necessary.

12.2.1 Physical composition

The idea that one object can be part of another is a familiar one. One’s nose is part of one’s head, Romania is part of Europe, and this chapter is part of this book. We use the general \( \text{PartOf} \) relation to say that one thing is part of another. Objects can be grouped into \( \text{PartOf} \) hierarchies, reminiscent of the Subset hierarchy:

\[
\text{PartOf}(\text{Bucharest}, \text{Romania})
\]
\[
\text{PartOf}(\text{Romania}, \text{EasternEurope})
\]
\[
\text{PartOf}(\text{EasternEurope}, \text{Europe})
\]
\[
\text{PartOf}(\text{Europe}, \text{Earth})
\]