This sounds wonderful in principle, until one realizes that it can only have one of two consequences: either hard problems cannot be stated at all, or they require exponentially large descriptions! However, the tractability results do shed light on what sorts of constructs cause problems and thus help the user to understand how different representations behave. For example, description logics usually lack negation and disjunction. Each forces first-order logical systems to go through a potentially exponential case analysis in order to ensure completeness. CLASSIC allows only a limited form of disjunction in the Fill and OneOf constructs, which permit disjunction over explicitly enumerated individuals but not over descriptions. With disjunctive descriptions, nested definitions can lead easily to an exponential number of alternative routes by which one category can subsume another.

12.6 REASONING WITH DEFAULT INFORMATION

In the preceding section, we saw a simple example of an assertion with default status: people have two legs. This default can be overridden by more specific information, such as that Long John Silver has one leg. We saw that the inheritance mechanism in semantic networks implements the overriding of defaults in a simple and natural way. In this section, we study defaults more generally, with a view toward understanding the semantics of defaults rather than just providing a procedural mechanism.

12.6.1 Circumscription and default logic

We have seen two examples of reasoning processes that violate the monotonicity property of logic that was proved in Chapter 7. In this chapter we saw that a property inherited by all members of a category in a semantic network could be overridden by more specific information for a subcategory. In Section 9.4.5, we saw that under the closed-world assumption, if a proposition \( a \) is not mentioned in \( KB \) then \( KB \) but \( KB \lor a \).

Simple introspection suggests that these failures of monotonicity are widespread in commonsense reasoning. It seems that humans often "jump to conclusions." For example, when one sees a car parked on the street, one is normally willing to believe that it has four wheels even though only three are visible. Now, probability theory can certainly provide a conclusion that the fourth wheel exists with high probability, yet, for most people, the possibility of the car's not having four wheels does not arise unless some new evidence presents itself. Thus, it seems that the four-wheel conclusion is reached, by default, in the absence of any reason to doubt it. If new evidence arrives—for example, if one sees the owner carrying a wheel and notices that the car is jacked up—then the conclusion can be retracted. This kind of reasoning is said to exhibit nonmonotonicity, because the set of beliefs does not grow monotonically over time as new evidence arrives. Nonmonotonic logics have been devised with modified notions of truth and entailment in order to capture such behavior. We will look at two such logics that have been studied extensively: circumscription and default logic.

\[^{\text{Recall that monotonicity requires all entailed sentences to remain entailed after new sentences are added to the KB. That is, if } KB \models a \text{ then } KB \models a.}\]
Circumscription can be seen as a more powerful and precise version of the closed-world assumption. The idea is to specify particular predicates that are assumed to be "as false as possible"—that is, false for every object except those for which they are known to be true. For example, suppose we want to assert the default rule that birds fly. We would introduce a predicate, say \( \text{Abnormal}_1(x) \), and write

\[
\text{Bird}(x) \land \neg \text{Abnormal}_1(x) \land \text{Flies}(x).
\]

If we say that \( \text{Abnormal} \) is to be circumscribed, a circumscriptive reasoner is entitled to assume \( \neg \text{Abnormal}_1(x) \) unless \( \text{Abnormal}_1(x) \) is known to be true. This allows the conclusion \( \text{Flies} \) (Tweety) to be drawn from the premise \( \text{Bird} \) (Tweety), but the conclusion no longer holds if \( \text{Abnormal} \) (Tweety) is asserted.

Circumscription can be viewed as an example of a model preference logic. In such logics, a sentence is entailed (with default status) if it is true in all preferred models of the KB, as opposed to the requirement of truth in all models in classical logic. For circumscription, one model is preferred to another if it has fewer abnormal objects. Let us see how this idea works in the context of multiple inheritance in semantic networks. The standard example for which multiple inheritance is problematic is called the "Nixon diamond." It arises from the observation that Richard Nixon was both a Quaker (and hence by default a pacifist) and a Republican (and hence by default not a pacifist). We can write this as follows:

\[
\text{Republican} \ (\text{Nixon}) \land \text{Quaker} \ (\text{Nixon}) \land \text{Abnormal}_2(x) \land \text{Abnormal}_3(x) \land \text{Pacifist}(x).
\]

If we circumscribe \( \text{Abnormal}_2 \) and \( \text{Abnormal}_3 \), there are two preferred models: one in which \( \text{Abnormal}_2(x) \) and \( \text{Pacifist}(x) \) hold and one in which \( \text{Abnormal}_3(x) \) holds. Thus, the circumscriptive reasoner remains properly agnostic as to whether Nixon was a pacifist. If we wish, in addition, to assert that religious beliefs take precedence over political beliefs, we can use a formalism called prioritized circumscription to give preference to models where \( \text{Abnormal} \) is minimized.

Default logic is a formalism in which default rules can be written to generate contingent, nonmonotonic conclusions. A default rule looks like this:

\[
\text{Bird}(x) : \text{Flies}(x) \land \text{Flies}(x).
\]

This rule means that if \( \text{Bird} \) (x) is true, and if \( \text{Flies}(x) \) is consistent with the knowledge base, then \( \text{Flies}(x) \) may be concluded by default. In general, a default rule has the form

\[
P : C \leftarrow J
\]

where \( P \) is called the prerequisite, \( C \) is the conclusion, and \( J \) are the justifications—if any one of them can be proven false, then the conclusion cannot be drawn. Any variable that

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*For the closed-world assumption, one model is preferred to another if it has fewer true atoms—that is, preferred models are minimal models. There is a natural connection between the closed-world assumption and definite clause KBs, because the fixed point reached by forward chaining on a definite clause KB is the unique minimal model. See page 258 for more on this point.*