circumscription or as an efficient logic programming language. The underlying theory of
stable model semantics was introduced by Gelfond and Lifschitz (1988), and the leading
answer set programming systems are DLV (Eiter et al., 1998) and SMODELS (Niemelä et al.,
2000). Brewka et al. (1997) give a good overview of the various approaches to nonmonotonic logic. Clark (1978) covers the negation-as-failure approach to logic programming and
Clark completion. Lifschitz (2001) discusses the application of answer set programming to
planning and to the frame problem in general. A variety of nonmonotonic reasoning systems
based on logic programming are documented in the proceedings of the conferences on Logic
Programming and Nonmonotonic Reasoning (LPNMR).

The study of truth maintenance systems began with the TMS (Doyle, 1979) and RUP
(McAllester, 1980) systems, both of which were essentially JTMSs. Forbus and de Kleer
(1993) explain in depth how TMSs can be used in AI applications. Nayak and Williams
(1997) show how an efficient incremental TMS called an ITMS makes it feasible to plan the
operations of a NASA spacecraft in real time.

This chapter could not cover every area of knowledge representation in depth. The three
principal topics omitted are the following:

**Qualitative physics**: Qualitative physics is a subfield of knowledge representation concerned
specifically with constructing a logical, nonnumeric theory of physical objects and processes.
The term was coined by Johan de Kleer (1975), although the enterprise could be said to have started in Fahlman’s (1974) BUILD, a sophisticated planner for constructing complex
towers of blocks. Fahlman discovered in the process of designing it that most of the effort
(80%, by his estimate) went into modeling the physics of the blocks world to calculate the
stability of various subassemblies of blocks, rather than into planning per se. He sketches a
hypothetical naive-physics-like process to explain why young children can solve BUILD-like
problems without access to the high-speed floating-point arithmetic used in BUILD’s physical
modeling. Hayes (1985a) uses “histories”—four-dimensional slices of space-time similar to
Davidson’s events—to construct a fairly complex naive physics of liquids. Davis (2008) gives
an update to the ontology of liquids that describes the pouring of liquids into containers.

De Kleer and Brown (1985), Ken Forbus (1985), and Benjamin Kuipers (1985) indepen-
dently and almost simultaneously developed systems that can reason about a physical system
based on qualitative abstractions of the underlying equations. Qualitative physics soon de-
veloped to the point where it became possible to analyze an impressive variety of complex physical systems (Yip, 1991). Qualitative techniques have been used to construct novel designs
for clocks, windshield wipers, and six-legged walkers (Subramanian and Wang, 1994). The
collection *Readings in Qualitative Reasoning about Physical Systems* (Weld and de Kleer,
1990), an encyclopedia article by Kuipers (2001), and a handbook article by Davis (2007)
provide good introductions to the field.

**Spatial reasoning**: The reasoning necessary to navigate in the wumpus world is trivial in
comparison to the rich spatial structure of the real world. The earliest serious attempt to
capture commonsense reasoning about space appears in the work of Ernest Davis (1986,
1990). The region connection calculus of Cohn et al. (1997) supports a form of qualitative
spatial reasoning and has led to new kinds of geographical information systems; see also
(Davis, 2006). As with qualitative physics, an agent can go a long way, so to speak, without
resorting to a full metric representation.