

and consumer applications. Note that there is no scientific claim that humans use HMMs to recognize speech; rather, HMMs provide a mathematical framework for understanding the problem and support the engineering claim that they work well in practice.

Machine translation follows the same course as speech recognition. In the 1950s there was initial enthusiasm for an approach based on sequences of words, with models learned according to the principles of information theory. That approach fell out of favor in the 1960s, but returned in the late 1990s and now dominates the field.

Neural networks also fit this trend. Much of the work on neural nets in the 1980s was done in an attempt to scope out what could be done and to learn how neural nets differ from “traditional” techniques. Using improved methodology and theoretical frameworks, the field arrived at an understanding in which neural nets can now be compared with corresponding techniques from statistics, pattern recognition, and machine learning, and the most promising technique can be applied to each application. As a result of these developments, so-called **data mining** technology has spawned a vigorous new industry.

DATA MINING

Judea Pearl’s (1988) *Probabilistic Reasoning in Intelligent Systems* led to a new acceptance of probability and decision theory in AI, following a resurgence of interest epitomized by Peter Cheeseman’s (1985) article “In Defense of Probability.” The **Bayesian network** formalism was invented to allow efficient representation of, and rigorous reasoning with, uncertain knowledge. This approach largely overcomes many problems of the probabilistic reasoning systems of the 1960s and 1970s; it now dominates AI research on uncertain reasoning and expert systems. The approach allows for learning from experience, and it combines the best of classical AI and neural nets. Work by Judea Pearl (1982a) and by Eric Horvitz and David Heckerman (Horvitz and Heckerman, 1986; Horvitz *et al.*, 1986) promoted the idea of *normative* expert systems: ones that act rationally according to the laws of decision theory and do not try to imitate the thought steps of human experts. The Windows<sup>TM</sup> operating system includes several normative diagnostic expert systems for correcting problems. Chapters 13 to 16 cover this area.

BAYESIAN NETWORK

Similar gentle revolutions have occurred in robotics, computer vision, and knowledge representation. A better understanding of the problems and their complexity properties, combined with increased mathematical sophistication, has led to workable research agendas and robust methods. Although increased formalization and specialization led fields such as vision and robotics to become somewhat isolated from “mainstream” AI in the 1990s, this trend has reversed in recent years as tools from machine learning in particular have proved effective for many problems. The process of reintegration is already yielding significant benefits

### 1.3.9 The emergence of intelligent agents (1995–present)

Perhaps encouraged by the progress in solving the subproblems of AI, researchers have also started to look at the “whole agent” problem again. The work of Allen Newell, John Laird, and Paul Rosenbloom on SOAR (Newell, 1990; Laird *et al.*, 1987) is the best-known example of a complete agent architecture. One of the most important environments for intelligent agents is the Internet. AI systems have become so common in Web-based applications that the “-bot” suffix has entered everyday language. Moreover, AI technologies underlie many