Routes to the Summit

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Achieving human-level artificial intelligence has turned out to be an extremely difficult task—much like climbing an unconquered peak. I exploit this mountain-climbing analogy to describe some of AI's history, achievements, detours, and prospects.

Many people have dreamed of intelligent artifacts. That's a good thing, because most expeditions begin with and are sustained by dreams. In mythology, we have the "Golden Maids" who served the god Hephaestus. And there is Galatea, a statue sculpted by Pygmalian and brought to life by Venus. Leonardo Da Vinci made sketches for a robot knight. And, of course, we have Karel Capek's "Rossum's Universal Robots" and Isaac Asimov's science fiction stories. But along with dreams, serious climbers must have some clues about how to conquer the mountain. Early clues about what would be needed to build intelligent artifacts can be found in Aristotle's syllogisms, Leibniz's ratiocinator, Boole's propositional algebra, and Frege's *Begriffsschrift* (concept writing).

Life itself provides several additional important clues. McCulloch and Pitts showed that networks of simple models of a biological neuron could compute all computable functions. George Miller and Noam Chomsky were among those who helped launch the field of cognitive science, providing hints about some of the higher-level functions implemented in our brains. And, because intelligent life forms evolved, perhaps the very processes and history of evolution can be employed to show us the way toward intelligent artifacts.

From engineering come additional important clues. Among these are feedback mechanisms, automatic machinery such as the Jacquard loom, and, most importantly, the computer. Turing and Shannon are among the first to offer detailed suggestions about how computer programs could play chess—a game that requires intelligence.

Armed with these ideas, several "base camps" were laid out. Frank Rosenblatt established camp "Neural Nets." Allen Newell and Herb Simon established camp "Cognitive Processes." John McCarthy established camps "Logical Methods" and "Commonsense." Marvin Minsky established camps "Heuristic Programming" and "Frames." Lotfi Zadeh established camp "Fuzzy," and Ed Feigenbaum established camp "Knowledge Engineering." There were many other camps as well, and all of them overlapped and shared ideas and resources. Many used the same "climbing gear," such as LISP and graph-searching methods.

At first the going was rather easy. Several preliminary pitches were scaled without too much difficulty. Climbers hailed the successes of the Perceptron, GPS, Dendral, Mycin, Shrdlu and the robots Shakey and Freddy. Ebullience reigned amongst the climbers. Optimistic predictions were made about summiting soon.

It wasn't long, however, before commentators pointed to difficulties ahead—ones such as "the combinatorial explosion," "Godel's barrier," "brittleness," and "the mesa phenomenon." They said that all of the early successes were achieved in "limited"

terrain. About the same time, some of the climbers abandoned the goal of reaching the summit, saying it was nobler and more important to use their gear to help people along the routes. Others claimed that none of the proposed routes would "go" and that alternative routes exploiting "emergence," "subsumption," or something entirely different would be required.

So, the climbers re-grouped. They improved much of their climbing gear and developed some new gear and techniques—Lisp machines, Bayes networks, sophisticated search strategies, Monte Carlo methods, Walksat, default logics, POMDPs, hidden Markov models, reinforcement learning, genetic programming, and support-vector machines, among others. Indeed, many of these methods were so powerful and useful that even more climbers abandoned the climb and detoured into green valleys to use their expertise on problems in biology, business, and defense—problems that didn't have very much to do with summitting.

Now, some fifty years after setting out for the peak, the remaining climbers are re-focusing on their original goal. Most of them agree that a combination of routes and techniques will be needed to reach the summit and that doing so might even take another fifty years or longer. More information about how the brain works is helping to inspire novel computational techniques. Much faster and less expensive computers allow more climbers to try out new strategies more quickly. Some really hard pitches have already been completed, such as automatically driving a Volkswagen 132 miles through desert terrain. My talk will explore some of these new developments and conclude with some personal guesses about promising routes ahead.

However long it takes, the summit is still there!

Short Biography

Nils J. Nilsson, Kumagai Professor of Engineering (emeritus) in the Department of Computer Science at Stanford University, received his PhD degree in electrical engineering from Stanford in 1958. He spent twenty-three years at the Artificial Intelligence Center of SRI International working on statistical and neural-network approaches to pattern recognition, co-inventing the A* heuristic search algorithm and the STRIPS automatic planning system, directing work on the integrated mobile robot, SHAKEY, and collaborating in the development of the PROSPECTOR expert system. He has published five textbooks on artificial intelligence. Professor Nilsson returned to Stanford in 1985 as the Chairman of the Department of Computer Science, a position he held until August 1990. Besides teaching courses on artificial intelligence and on machine learning, he has conducted research on flexible robots that are able to react to dynamic worlds, plan courses of action, and learn from experience. Professor Nilsson served on the editorial boards of the journal *Artificial Intelligence* and of the *Journal of Artificial Intelligence Research*. He was an Area Editor for the *Journal of the Association for Computing Machinery*. He is a past-president and Fellow of the American Association for Artificial Intelligence and is also a Fellow of the American Association for the Advancement of Science. He was a co-founder of Morgan Kaufmann Publishers, Inc. Professor Nilsson is a foreign member of the Royal Swedish Academy of Engineering Sciences and is a recipient of the IEEE "Neural-Network Pioneer" award, the IJCAI "Research Excellence" award, and the AAAI "Distinguished Service" award.