J. Expt. Theor. Artif. Intell. 9(1997)337–338

# Robotics and artificial intelligence

NILS J. NILSSON

*Robotics Laboratory, Department of Computer Science, Stanford University, Stanford, CA 94305, USA*
e-mail: nilsson@cs.stanford.edu

*Received 21 March 1996*

At Stanford University, one of the divisions of the Department of Computer Science is called *Artificial Intelligence and Robotics*. This name implies that we think there is a connection between the two. Is there? After all, much of robotics involves mathematics quite different from that of the rest of AI: matrix algebra for dealing with changing coordinate systems, differential equations for analysis of robotic control systems, spectral analysis for studying sensor signal processing, and potential functions for path planning. Yet, if robots are ultimately to be as flexible, robust, and useful as we want them to be, it seems clear that these mathematical techniques will need to be augmented by the representational, reasoning, and learning methods of AI.

Perhaps the first attempt to combine AI methods with a robot system was *Shakey*, the mobile robot developed at SRI (then Stanford Research Institute) during the late 1960s. In fact, that attempt at integration inspired inventions that are now regarded as fundamental in artificial intelligence—the STRIPS planning system, the A* heuristic search algorithm, the 'three-level architecture' for intelligent robots, and explanation-based learning of macro-operators, to name just a few. The architecture used for Shakey combined high-level symbolic reasoning and planning, a declarative model of useful facts, intermediate and low-level actions, path planning, execution monitoring, and visual sensing. Unfortunately, Shakey did not leave a trail of successor projects, and thus several of the lessons learned from this first 'implemented architecture on a physical agent' had to be re-discovered.

We are in a much better position now to build integrated robot systems than we were *circa* 1970. Then, 200000 36-bit words of RAM (called core-memory in those days) counted as a powerful computer system. Transistors were discrete components with solder-dipped connections rather than microscopic spots of silicon layered on a chip. Frame grabbers for robot vision were much bigger and slower. Very little computation could be done on board the robot. The progress in computational hardware since then has been dramatic. There have been similar advances in sensors, effectors, and battery technology.

AI has also made substantial headway in the last twenty-five years. Neural networks are able to learn complex perceptual functions. Active, stereo vision enables real-time perception of the environment. Hierarchical, nonlinear planning enables the synthesis of elaborate plans. Bayesian belief networks permit reasoning with uncertain information. Explanation-based methods can be applied to learning important control heuristics. Advances in speech understanding and natural language processing allow flexible communication with human users.

Now, twenty-five years later, in combination robotics and AI technologies can be pursued even more productively. I hope that the sponsors of AI and robotics research see the potential as clearly as do the contributors to this volume. As in any attempt to combine disparate abilities into a smoothly functioning system, the key will be the architecture. I hope several different designs will be explored, and that out of this variety will emerge elegant ways to combine deliberative reasoning (when that is appropriate) with fast reaction (when that is necessary).

A nice little poem by W. H. Auden summarizes for me the awful fate of a robot without AI and AI without robotics:

Those who will not reason
Perish in the act;
Those who will not act
Perish for that reason.