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Resource-Bounded Reasoning in Phoenix

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I started working in resource-bounded reasoning as part of the PHOENIX project (Cohen *et al.* 1989; Hart & Cohen 1990; Greenberg & Westbrook 1990), while a graduate student in the Experimental Knowledge Systems Laboratory (EKSL) at UMass, Amherst. The PHOENIX problem domain is forest fire fighting, for which EKSL built a sophisticated computer simulation of forest fires in Yellowstone National Park (based on satellite data) and of autonomous agents that put out the fires. The PHOENIX system consists of an instrumented discrete event simulation, an autonomous agent architecture that integrates multiple planning methods, and a hierarchical organization of agents capable of improving their fire-fighting performance by adapting to the simulated environment. The PHOENIX agent architecture includes several innovative features that support adaptable planning under real-time constraints, including a least-commitment planning style called lazy skeletal refinement and a combination of reactive and deliberative planning components operating at different time scales. The problem involves resource-bounded reasoning because the simulator ensures that the fire continues to burn while the agents are planning and acting. The deadlines are somewhat soft, because the agent can gain time by sacrificing more forest, but it sets a deadline for itself as part of committing to a plan, and it is costly to replan at that point. In any event, there is a natural time pressure on the agent, which it can monitor by observing the fire as well as its own progress.

As part of my dissertation (Anderson 1995), I implemented a discrete-event simulation substrate to support empirical research in real-time planning, addressing some of the flaws we discovered in the original PHOENIX simulator. I also re-implemented PHOENIX to use this new substrate. This substrate, called MESS, extends ordinary discrete-event simulators with the ability to have multiple computational streams, which is how the PHOENIX agents think. Furthermore, the duration of these computational streams is controlled by an explicit database, thereby giving the researcher a great deal of control over the simulation (Anderson & Cohen 1995; 1996).

My current research interests are in employing PHOENIX in two ways, specifically attacking its lazy-skeletal refinement planning algorithm.

First, I want to implement more general, classic, search-based planners (such as UCPOP (Barrett *et al.* 1993)) into the PHOENIX environment, to replace the existing lazy skeltal refinement planner. While I expect UCPOP to do poorly compared to a planner specifically designed for the PHOENIX environment, the comparison will show the advantages that the existing planner gets from its algorithm and domain knowledge. Factoring the domain knowledge and search control from the generic planner will allow the PHOENIX planner to be generalized to other resource-bounded planning problems.

Secondly, I want to extend the planner with algorithms that are explicitly aware of the passage of computational time and even anticipate it, so that when the agent sets a deadline for itself, it takes into account its own computation time. Currently, the agent estimates the time necessary for the real-world actions (such as movement and digging fireline), but not for planning actions, such as thinking and monitoring. Furthermore, the time estimation is done on a fairly *ad hoc* basis, and it should instead be done in a more introspective way, with the agent aware of its own planning actions and the nature of its real-world actions.

References

Anderson, S. D., and Cohen, P. R. 1995. The duration of deliberation. In *Proceedings of the 1995 IJCAI workshop on Anytime Algorithms and Deliberation Scheduling.* IJCAI.

Anderson, S. D., and Cohen, P. R. 1996. On-line planning simulation. In *Proceedings of the Third Interna-*

tional Conference on Artificial Intelligence Planning Systems. AAAI Press.

Anderson, S. D. 1995. *A Simulation Substrate for Real-Time Planning.* Ph.D. Dissertation, University of Massachusetts at Amherst. Also available as Computer Science Department Technical Report 95–80.

Barrett, A.; Golden, K.; Penberthy, J. S.; and Weld, D. S. 1993. UCPOP user's manual (version 2.0). Technical Report 93-09-6, Department of Computer Science and Engineering, University of Washington.

Cohen, P. R.; Greenberg, M. L.; Hart, D. M.; and Howe, A. E. 1989. Trial by fire: Understanding the design requirements for agents in complex environments. *AI Magazine* 10(3):32–48.

Greenberg, M. L., and Westbrook, D. L. 1990. The Phoenix testbed. Technical Report COINS TR 90–19, Computer and Information Science, University of Massachusetts at Amherst.

Hart, D. M., and Cohen, P. R. 1990. Phoenix: A test bed for shared planning research. In *Proceedings of the NASA Ames Workshop on Benchmarks and Metrics.*