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Reflection in Action: Meta-Reasoning for Goal-Directed Autonomy

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Abstract

In this talk, I will review my laboratory's work on meta-reasoning for goal-directed autonomy. We are exploring how meta-reasoning in intelligent agents enables self-adaptation and how self-adaptation promotes goal-directed autonomy. In particular, we are investigating how an agent's model of its own design enables to the agent to adapt its design to recover from failures (failure-driven retrospective adaptation) and to achieve new goals (proactive, goal-directed adaptation). I will illustrate these issues with examples from the interactive turn-based strategy game called Freeciv.

Meta-Reasoning for Goal-Directed Autonomy

Autonomy is a central characteristic of intelligent agents. Since autonomous agents live in dynamic environments, they must adapt themselves to changes in the world. It is useful to make a few distinctions here. Firstly, adaptations to an agent can be retrospective (i.e., when the agent fails to achieve a goal in its given environment), or proactive (i.e., when the agent is asked to operate in a new task environment). Secondly, adaptations can be either to the deliberative element in the agent architecture, or the reactive element, or both. Thirdly, adaptations to the deliberative element may be modifications to its reasoning process (i.e., to its task structure, selection of methods, or control of reasoning), or to its domain knowledge (i.e., the content, representation and organization of its knowledge), or both.

For the past two decades, my laboratory has been exploring the thesis that an agent's model of its own design may enable the agent to adapt itself both to recover from failure (failure-driven, retrospective adaptation) and to achieve new goals (goal-directed, proactive adaptation). In particular, we have been investigating the hypothesis that an agent self-model that specifies the teleology of the agent's design (i.e., a model that describes how the agent's methods use knowledge to accomplish its tasks) affords localization of the modifications needed for goal-directed as well as failure-driven. We have developed an agent description language called TMKL (Murdock & Goel 2008) for specifying the teleology of an agent's design, i.e., for specifying the goals and subgoals of the agent, the domain knowledge of the agent, and the methods of the agent that use domain knowledge and compose the subgoals into the goals. TMKL is as expressive but more explicit than HTN (Hoang, Lee-Urban & Munoz-Avila 2005).

In addition, we have developed a series of knowledge systems that use agent self-models for enabling different kinds of model-based adaptations in different conditions. Autognostic (Stroulia & Goel 1996, 1997, 1999), for example, performs failure-driven, retrospective reconfiguration of the reasoning strategies in the deliberative component of a planning agent. Autognostic actually is a knowledge-based shell in which different agents can be encoded and adapted. Reflecs (Goel et al. 1998) is an encoding of a reactive agent in Autognostic; it modifies the design of a reactive agent to recover from a class of failures. We found that agent self-models enable self-monitoring of the agent's behaviors as well as self-diagnosis of the agent's design when the agent's behaviors failed to achieve a goal.

REM (Murdock & Goel 200, 2003, 2008) performs goal-directed proactive adaptation, for example adapting a planning agent designed to assemble a device from its components to achieve the new goal of disassembling the device. We discovered that TMKL self-models enable an agent to transfer and adapt its task-method structure for the task it was designed to new similar, closely related tasks assigned to it. REM too is a knowledge-based shell for encoding different planning agents. It uses the TMKL description of the planning agent to localize the modifications needed to achieve new goals, and then uses methods such as graph-planning and Q-learning to accomplish the modifications. This enables REM to localize situated learning (Ulam et al. 2008).

Augur (Jones & Goel 2007) is a system for self-diagnosis and repair of an agent's domain knowledge. In particular, Augue uses meta-knowledge of predictions made at intermediate nodes in a classification hierarchy for self-diagnosis of incorrect classification knowledge. Augur encodes this predictive meta-knowledge in the form of empirical verification procedures. Given a classification hierarchy that results in an incorrect class label, the empirical verification procedures evaluate predictions made at the intermediate nodes, identify the nodes responsible for the classification error, and help repair the knowledge at the nodes

Reflection in Action

In recent work, my colleagues and I are investigating the above ideas in the context of the interactive turn-based strategy games. We know that game designs evolve rapidly but incrementally. Further, when a game evolves, the software agents that play the game should evolve as well. However, the current practice of adapting game-playing agents to incremental changes in game designs is *ad doc* because at present there is little systemization of designs of game-playing agents or understanding of mechanisms for modifying their designs. We hypothesize that scaling up game-agent adaptation to end game-users requires interactive tools that make the designs of game-playing agents transparent to game users, help generate design modifications, and automatically translate modifications to agent designs into modifications to their codes. My software engineering colleague Spencer Rugaber and I are developing an interactive technology (called GAIA) for supporting adaptation of game-playing software agents as game designs evolve. GAIA contains a TMKL model of software agents that play Freeciv, an open-source variant of the turn-based strategy game called Civilization (www.freeciv.org). As the game design evolves (e.g., a new rule is introduced into the game), GAIA uses the TMK model to analyze the modifications needed to the agent design and propagates the changes all the way down to the program code (Jones et al. 2009). This project is enabling us to build on and pull together various elements of our previous work on meta-reasoning for self-adaptation and goal-directed autonomy.

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