Chapter X

Bayesian Agencies in Control

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ABSTRACT

Most agent architectures implement autonomous agents that use extensive interaction protocols and social laws to control interactions in order to ensure that the correct behaviors result during run-time. These agents, organized into multi-agent systems in which all agents adhere to predefined interaction protocols, are well suited to the analysis, design and implementation of complex systems in environments where it is possible to predict interactions during the analysis and design phases. In these multi-agent systems, intelligence resides in individual autonomous agents, rather than in the collective behavior of the individual agents. These agents are commonly referred to as "next-generation" or intelligent components, which are difficult to implement using current component-based architectures.

In most distributed environments, such as the Internet, it is not possible to predict interactions during analysis and design. For a complex system to be able to adapt in such an uncertain and non-deterministic environment, we propose the use of agencies, consisting of simple agents, which use probabilistic reasoning to adapt to their environment. Our agents collectively implement distributed Bayesian networks, used by the agencies to control behaviors in response to environmental states. Each agency is responsible for one or more behaviors, and the agencies are structured into heterarchies according to the topology of the underlying Bayesian networks. We refer to our agents and agencies as "Bayesian agents" and "Bayesian agencies."

Due to the simplicity of the Bayesian agents and the minimal interaction between them, they can be implemented as reusable components using any current component-based architecture. We implemented prototype Bayesian agencies using Sun's Enterprise JavaBeans™ component architecture.

INTRODUCTION

For a system to exhibit computational intelligence, it must be able to learn from and adapt to changes in its environment. Most distributed environments are characterized by uncertainty and non-determinism. Bayesian networks provide the ideal mechanism for systems inhabiting environments such as these, to learn from, reason about and adapt to changes in their environment. Our research focuses on the implementation of distributed Bayesian networks using simple agents organized into agencies. These agencies are structured into heterarchies according to the structure of the Bayesian networks that they collectively implement. Each agency is responsible for one or more behaviors. We call these agents and agencies "Bayesian agents" and "Bayesian agencies."

This chapter is organized as follows: it begins by giving a background on the underlying technologies that we use in our research. We define agents, agencies, heterarchies, intelligence and artificial life. We further describe Bayesian networks, Bayesian belief propagation and Bayesian learning algorithms.

Next we describe how these agencies collectively adapt to environmental states using a simple Web personalization example. We further describe emergent belief propagation in the Bayesian agencies and a prototype implementation thereof using a component-based architecture.

Then we describe future research and in finally we give our conclusion.

BACKGROUND

Agents, Agencies and Heterarchies

There are two different approaches to the definition of the concepts of agents in the research community. In the first (most popular) approach, agents are autonomous entities as reflected in the following definition:

An agent is an encapsulated computer system situated in some environment and capable of flexible, autonomous action in that environment in order to meet its design objectives (Jennings, 2001).

In the second approach, which was started by Minsky (1988), simple, unintelligent agents are organized into agencies, which in turn can be organized into