Dynamic Workflow Composition Using Markov Decision Processes

Prashant Doshi, University of Illinois at Chicago, USA
Richard Goodwin, IBM T.J. Watson Research Center, USA
Rama Akkiraju, IBM T.J. Watson Research Center, USA
Kunal Verma, University of Georgia, USA

ABSTRACT

The advent of Web services has made automated workflow composition relevant to Web-based applications. One technique that has received some attention for automatically composing workflows is AI-based classical planning. However, workflows generated by classical planning algorithms suffer from the paradoxical assumption of deterministic behavior of Web services, then requiring the additional overhead of execution monitoring to recover from unexpected behavior of services due to service failures, and the dynamic nature of real-world environments. To address these concerns, we propose using Markov decision processes (MDPs) to model workflow composition. To account for the uncertainty over the true environmental model, and for dynamic environments, we interleave MDP-based workflow generation and Bayesian model learning. Consequently, our method models both the inherent stochastic nature of Web services and the dynamic nature of the environment. Our algorithm produces workflows that are robust to non-deterministic behaviors of Web services and that adapt to a changing environment. We use a supply chain scenario to demonstrate our method and provide empirical results.

Keywords: B2B e-commerce; probabilistic planning; Web services; workflow

INTRODUCTION

As service-oriented architectures become more widely deployed, it will become more common for enterprises to provide a Web services based interface to their core business systems. The task of business process integration and management (BPIM) will then involve linking together both intra-enterprise and inter-enterprise services to achieve the desired business objectives. As we illustrate in Figure 1, the workflows that arise out of BPIM will be composed of invocations of Web services based interfaces of the enterprise business systems.

Prevalent techniques for BPIM and the analogous workflow composition problem are time-consuming and often involve the use of custom and proprietary technology for connecting business partners. Such techniques often produce inflexible workflows, which are expensive to maintain. The advent of Web services has the
potential to significantly reduce the cost by introducing standard protocols and helping to automate the process. Specifically, the ability to dynamically discover and bind to Web services using Web services discovery mechanisms facilitate automated workflow compositions.

If we view workflow composition as a goal-oriented process, AI-inspired planning techniques appear suitable for the task. Preliminary efforts in this respect (Wu, Sirin, Hendler, Nau, & Parsia, 2003; Sheshagiri, desJardins, & Finin, 2003; Carman, Serafini, & Traverso, 2003) utilize classical STRIPS-style planning algorithms and their variants that assume deterministic behavior of Web services. These efforts represent early steps in automating the workflow composition process; however, they are limited in several ways. Classical planning algorithms do not consider the inherent uncertainty in Web services behaviors while generating the workflow. They assume a static environment and do not present a principled method to manage workflows in dynamic environments, and they do not include a method for selecting between candidate workflows.

In this paper, we propose using decision-theoretic planning to automate Web services based workflow composition. Decision-theoretic planning provides a principled method to generate robust workflows, while simultaneously relaxing many of the unrealistic assumptions characterizing classical planning algorithms. Specifically, decision-theoretic planning formalisms model the uncertainty present in the process, and produce a plan that optimally balances the expected risks and rewards. Decision-theoretic planning is based on the widely accepted Kolmogorov axioms of probability and the axiomatic utility theory. In this paper, we utilize a decision-theoretic planning formalism called Markov decision processes (MDPs) (Puterman, 1994; Russell & Norvig, 2003) to model the problem of workflow composition. Our method models both the stochastic nature of services and the dynamic nature of the environment producing workflows that are robust and adaptive. The solution of a MDP produces a policy that optimally guides a stateful workflow towards its goal, based on the current model of the dynamic environment. We assume that neither is the true model known a priori nor is it static. To deal with the lack of prior information and the possibly changing environment, we intersperse policy computation with Baye-
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