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A multi-agent reinforcement learning approach to dynamic service composition

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ABSTRACT

As a promising implementation of software systems, service composition has attracted significant attention and research, which constructs complex and value-added applications by composing existing single services to reduce the deployment time and cost. However, as the services on the Internet and the external environment are frequently changeable, these demand the service composition must be adaptive and dynamic to address these changes automatically. Therefore, this paper describes a multi-agent reinforcement learning model for the dynamic optimization of web service composition. In this model, agent can utilize reinforcement learning algorithms to interact with environment in real time to compute optimal composition strategy dynamically, and multi-agents mechanism can keep higher effectiveness in contrast to single-agent reinforcement learning. We propose a distributed Q-learning algorithm, which decompose the task into many sub-tasks and make every agent focus on own sub-task, to accelerate the convergence rate. In addition, we also introduce experience sharing strategy to improve the efficiency. As a result, these methods allow composite service to dynamically adjust itself to fit a varying environment, where the properties of the component services continue changing. Finally, a series of comparable experiments with traditional Q-learning algorithm demonstrate that our algorithms have certain validity, higher efficiency and obvious advantages.

1. Introduction

Web service is an integration technology that aggregates Web-based applications using open standards over an Internet protocol backbone. A web service is considered self-contained and self-describing module for rapid, low-cost composition of distributed applications. Service Oriented Computing (SOC) espouses the concept of software-as-a-service and it provides a promising paradigm to support rapid, low-cost development of distributed applications in heterogeneous environments, where services are utilized as fundamental elements for application development [22]. In this paradigm, data, software and hardware can all be encapsulated as services shared on the Internet. Based on a considerable number of available services, application creators can transfer more energy from the establishment of the infrastructures to the deployment of business logics.

A single Web service may not meet the requirements of complex business transactions due to its limited functionality and complexity. Consequently, the development of new services through the composition of existing ones has attracted

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significant momentum as a means to integrate heterogeneous web applications and to realize more complex workflows. In the current SOC technology, this composition is usually carried out by human engineers. Note that most web services keep evolving in their whole life-cycle and the external environment also is highly dynamic, service engineers cannot always foresee all the changes and the manual service composition seems inadequate for dynamic situation. Therefore, dynamic service composition is regarded as a crucial functionality for the Web of the future. Different technologies of computational intelligence have been investigated for solving the problem of dynamic service composition.

Automatic Service Composition (ASC) technology has been suggested to automatically discover, select, and compose multiple individual services to satisfy various requirements. AI planning is a typical type of techniques used to automate Web services composition [6,10,16,25]. In [11] and [10], the authors proposed the application of MDPs (Markov Decision Processes) in Web service composition, which assumed a fully observable world and require explicit reward functions and state transition functions. Such requirements are too strict to a real world scenario. In general, these early researches on automatic service composition did not consider the nonfunctional attributions of services. They usually return the service composition results with fewer services or less depth [9].

As a subdiscipline of distributed artificial intelligence (DAI), multi-agent technique has attracted more and more attention with its outstanding advantages, such as more computing power, modular solution, scalability and flexibility, which extremely suit for the each requirement of service composition. In a multi-agent system(MAS), every agent can work as an independent computing entity, and consequently this pattern can achieve a distinct advantage about the computational efficiency in large and complex scenarios. Moreover, multi-agent technique also has certain efficiency in service composition process with their learning and good interaction ability with external environment. Gutierrez-Garcia et al. [12] described the behavior of services with the colored Petri net, and utilized the multi-agent technology to service orchestration in the context of cloud computing. The method can bring high efficiency, while its adaptivity is relatively short, which is another vital issues in service composition with large number of services.

As a typical technology of machine learning for planning and optimization in dynamic environment, Reinforcement learning concerns how an agent ought to take actions in an environment so as to maximize some notion of cumulative reward [26]. Instead of being set up the desired actions in advance, the agent emulates the learning behaviors of human beings and normally follows an trial and error process to find a suit action to obtain the most reward. This learning mechanism can ensure it has the inherent adaptability for a dynamic environment. Wang et al. [32] conducted the process of service composition based on reinforcement learning (RL), so as to avoid complex modeling of the real world and compute the optimal composition policy effectively. However, when the state space is huge, simulations over sample states and rewards have to be considered, as well as online stochastic search.

In fact, reinforcement learning does not necessarily rely on a single agent to search the complete state-action space to obtain the optimal policy. In a real human environment, people do not learn everything through their own discovery, but exchange information and learn from the others. This multi-agent approach can be applied to the Web service environment too. For example, consider the situation that two or more agents work together to search for an optimal service composition simultaneously. They can share the information about the best services and policies in the exploration process. The resulting parallelism can help us boost the efficiency of reinforcement learning.

In this paper, we present a novel mechanism based on multi-agent reinforcement learning to enable adaptive service composition. In this mechanism, the agent can learn the environment knowledge online with its learning ability and work out effective adaptive policy to suit the dynamic environment. We model the service composition process as a Markov Decision Process (MDP)to adapt to the dynamic internal environment and different user requirements. This model utilizes the sematic web markup language to describe web service. In this model, multiple alternative services and workflows can be incorporated into a single service composition for each agent. The model proposed in this paper extends the reinforcement learning model that we have previously introduced in [32].

We present a distributed Q-learning algorithm to speed up the learning rate. The algorithm conducts the task decomposition before the learning process with the theory of articulation state. This decomposition makes each agent work for certain sub-goal in a reduced search space. In addition, we also introduce a sharing strategy into the composition process to reduce the time of convergence. This strategy makes agents share information with each other, and thus one agent can use the policies explored by the others. Since the learning process continues throughout the whole cycle of a service composition, the composition can automatically adapt to the changes and evolvements come from both environment and its component services. Finally, we conduct a series of simulated experiments to test the validity and effectiveness of the algorithm proposed in this paper. Because the algorithm was extended from traditional Q-learning algorithm, we compare our two algorithms with it in every aspect to evaluate the efficiency of our algorithm. The results show our algorithm has more effectiveness.

2. Related work

With the development of web services, dynamic web service composition has received increasing attention. In this section, we briefly discuss several approaches which mainly used to solve the dynamic web service composition and improve efficiency via AI planning from aspects of web service composition, graph planning, prediction algorithm, multi-agents techniques, because those aspects are becoming a hot topic following the trend of dynamic environment and era of big data.