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To cite this version:
Siri Fagernes, Alva Couch. Scalability and Information Exchange Among Autonomous Resource Management Agents. 10th IFIP International Conference on Autonomous Infrastructure, Management and Security (AIMS), Jun 2016, Munich, Germany. pp.160-164, 10.1007/978-3-319-39814-3_18. hal-01632749

HAL Id: hal-01632749
https://hal.inria.fr/hal-01632749
Submitted on 10 Nov 2017

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Scalability and Information Exchange among Autonomous Resource Management Agents

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Abstract. We study a scenario of autonomous resource management agents, aiming for fulfilling a management goal of balancing value of service with cost. We aim for a model of management based on fully distributed knowledge, avoiding traditional challenges associated with centralized approaches. Our results indicate that lack of information about the actions of other agents can be mitigated via direct observation of each agent’s environment.

Keywords: resource management, autonomous agents, cloud management, reactive approaches, decentralized knowledge

1 Introduction

We present a theoretical model of distributed resource management, which is analysed through simulations. The model involves autonomous agents that must collaborate, either directly or indirectly, to achieve a common management goal (balance cost and value). Our previous work has focused on studying the coordination of only two agents, whose primary task is to control resource usage in the system they operate, and try to estimate, based on varying information access, how to adjust their current resource level optimally.

In this paper, we study the coordination of a larger group of autonomous resource management agents, in the setting where they share a common resource pool. The main research objective is to determine whether the agents can achieve their common goal in an optimal manner without exchanging local information with each other. We see that individual observations of behaviour observed by each agent can replace information exchanged directly among the agents, which increases scalability.

2 Related Work

An automatic resource management process can be either \textit{reactive} \cite{1} or \textit{predictive}, determined by how resources are automatically adjusted. The predictive
approaches are typically based on having access to a complete model of the sys-
tem, which (in theory) gives the ability to provide QoS guarantees and a more
detailed view of the dynamics of the system. The major challenge of such ap-
proaches is getting access to such knowledge, if it is even possible. Examples of
model-based approaches are [2], [3], [4], [5], [6] and [7].

Reactive approaches are designed to make appropriate decisions when one
lacks complete knowledge of the system model, and are used in complex systems
for decision making. A common challenge in reactive approaches is that the
learning algorithm responsible for making decisions requires a training period
for gathering data to make appropriate action decisions. Examples of reactive
approaches are presented in [1], [8], [9], [10], [11], and [12].

Most of the existing approaches are based on centralized knowledge. This
means they have the advantage of one component having complete system knowl-
dge, which avoids the complexity of coordination and communication overhead
in distributed approaches. However, centralized approaches in larger complex
systems – cloud systems – have several drawbacks, including limited scalability,
single point of failure issues, and potential bottlenecks.

3 Method and Approach

Our management scenario consists of ten autonomous resource management
agents $Q_i$, $i \in [1, 10]$, where $Q_i$ controls a separate resource variable $R_i$. Each re-
source variable (or component in the system) contributes to delivering a service
$S$. The main objective of management is to achieve efficient management of all
the different system resource variables, with the objective to achieve a balance
between cost and produced value. To determine value of the delivered service,
the performance metric $P$ represents job throughput, i.e., the reciprocal of re-
sponse time. The response time will depend on how the system is able to cope
with current load, which is defined as an arrival rate of requests. The system
performance is hence defined as the request completion rate, and is modeled
approximately as

$$P = B - \frac{\gamma L}{R}$$  \hspace{1cm} (1)

where $B$ is the baseline performance (the performance when the system is not
affected by load). $\gamma$ is a constant representing resource-intensitivity, i.e. increased
$\gamma$ represents a service in which the service requests are more resource-intensive.
Further, we define associated value of service to be proportional to throughput,
so that

$$V = \alpha P = \alpha \sum_{i=1}^{10} P_i.$$  \hspace{1cm} (2)

Similarly, cost $C$ is proportional to resource use $R$, so that

$$C = \beta R.$$  \hspace{1cm} (3)
The autonomous agents (resource controllers), which are responsible for making decisions on resource use and adjustments, do not have access to knowledge of this theoretical model of the system’s performance. Each agent observes how system value $V$ changes with changes in $R_i$, $\Delta V/\Delta R_i$, and based on the local knowledge of associated cost $C(R_i)$, the closure operator can make an estimate of how net value $N = V - C$ changes with $R_i$, by calculating $\Delta N/\Delta R_i$. If this value is positive, the controller will increase $R_i$, and if it is negative, decrease $R_i$. This hill-climbing strategy will converge to a global optimum whenever the objective function $N$ is convex.

The agents have a perception of how system value depends on resource use. The theoretically correct global value is defined as

$$V = \alpha(B - \frac{\gamma L}{R_1} - \frac{\gamma L}{R_2} - \ldots - \frac{\gamma L}{R_{10}})$$  \hspace{1cm} (4)

In our experiments, the agents assume that the value-resource relationship is modelled as

$$V = a \frac{L}{R} + b.$$  \hspace{1cm} (5)

4 Results

When each operator receives individual value feedback, no external information about other operators is needed. When the operator has a semi-accurate model of the system dynamics and current system load, all operators perform very close to optimal, as seen in Figure 1.

Providing less information (no load information) reduces the precision of the results (Figure 2a), but the performance (achieved net value) is quite close to the theoretical optimum (Figure 2b).
Fig. 2: 10 operators, each controller lacks information about system load. $\gamma = 1$ for all agents.

5 Conclusion and Further Work

Although there has been significant research efforts aimed at achieving fully decentralized management of larger complex systems, most proposed solutions so far has been based on either pure centralization or partly centralization based on delegation of responsibility. Our work has been an attempt to achieve pure decentralized management. The goal of our approach is trying to come up with an intermediate approach between delegated management and agent based management, in which there is higher predictability and more accurate goal achievement.

This study indicates that to achieve self-optimising behaviour among autonomous agents working towards the same goal, without direct coordination, excessive information exchange or centralized knowledge, is the ability to monitor their individual behaviour. This means that developing efficient feedback mechanisms is a crucial factor to reduce the need for global information exchange.

One particular issue that we have not studied, is how the precision of our proposed model is affected by more heavily varying system load. Also, to test the robustness of the model, this needs to be implemented in a real scenario.

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