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Towards a fuzzy bigraphical multi agent system for cloud of clouds elasticity management ☆

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ABSTRACT

A major ingredient that encourages the wide adoption of Cloud Computing solution is their ability to allocate and des-allocate resources in automatic and optimal manner according to customers' needs or what is referred to *Cloud Elasticity*. Indeed, Cloud Elasticity is influenced by different dependable factors, principally: unpredictable variable workload, Cloud resource limitation, possible system failures, etc. Thus, ensuring Cloud elastic behavior of systems is a very challenging task. Our first contribution is to propose a Multi Agent System for Cloud of Clouds Elasticity Management (*MAS-C2EM*). The interacting agents cooperate to ensure Cloud Elasticity through a set of strategic solutions at both micro (Intra Cloud Infrastructure/Intra Cloud Software) and macro (Inter Cloud) levels. We define the Inter Cloud Elasticity strategy using a novel Top Clouds Cooperation solution. The given strategy is based on the fuzzification of Pareto dominance mechanism. In the second contribution, we adopt Bigraphical Reactive System (BRS) as an effective formalism to specify the *MAS-C2EM* at both structural and behavioral aspects, resulting in the definition of Bigraphical Multi Agent System for Cloud of Clouds Elasticity Management (*BigMAS-C2EM*) semantical model. Besides, we formally analyze the model via some inherent properties using the model checker BigMC.

1. Introduction

Cloud Computing [1] is being positioned as one of the most popular paradigms appeared in the last decade, in both industrial and academic worlds. This new paradigm proposes a new delivery model to do too much better for too much cheaper. The new delivery model is based on a simple principle that consists of providing a set of virtualized resources as on demand services. Those services are delivered according to three fundamental models: Infrastructure as a Service (IaaS); Platform as a Service (PaaS); and Software as a Service (SaaS).

One of the key factors motivating the popularity of Cloud Computing is *Elasticity* property, which is considered as unique characteristic of Cloud compared to the other technologies. Elasticity [2] is the degree to which a system is able to adapt to workload changes by allocating and des-allocating resources in autonomic manner, such that at each point in time the available resources match the current demand as close as possible. Thus, the Cloud elastic service should be able to collect new computing resources when their workload is increased, but also to discard any exceeding resources when workload is decreased. According to Galante and de Bona classification [3], the Cloud elastic resource provisioning is ensured through three elementary methods: Horizontal scale, Vertical scale, and Migration.

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Due to Cloud rapid elasticity, Cloud consumer has the illusion of infinite computing resources that can be provisioned, at any time, with any quantity. However, Cloud resources are limited and a single Cloud does not have infinite resources. This means that resources cannot be scaled up infinitely. A single Cloud may face a situation, where there is no more available resources to cope with increasing requests. This dilemma is considered as one of the most important reason that encourages the Multi or Inter Cloud solution adoption. Multi Cloud or Inter Cloud idea first appears at Cisco Systems which coined the term Inter Cloud as an interconnected global Cloud of Clouds that takes of the known term Internet, network of networks [4]. Inter cloud is an interconnected global Cloud of Clouds that enables the Cloud systems to cooperate with each other, allowing each Cloud to tap into the resources of other Clouds. Such mechanism enables Cloud system to continue the delivery of guaranteed service levels, even when unexpected load levels occur or disasters strike that can easily overburden a single Cloud system and lead to unreliable and interrupted services [5]. In Cloud Elasticity context, the Inter Cloud creates an elasticity new dimension, often called Inter Cloud Elasticity. Such solution defines a structural scale at Cloud level. This consists to switch from a Cloud provider to another one in case of insufficient local resources to respond incoming requests.

Recently, considerable researches are dedicated to Cloud Elasticity improvement [3,6]. However, most of them care about elasticity control or management at micro level (Intra Cloud), while few works examine the macro level (Inter Cloud). Considering Cloud system critical situations (resources unavailability or system failures), that influence directly on Intra Cloud elasticity solutions and automatically threatening the Cloud elastic behavior. It is imperative to envisage a solution that considers the elasticity control at both Intra and Inter Cloud levels. Such solution guaranteed a full coverage of all system critical situations and ensures Cloud elastic behavior.

Cloud computing is one of the most complex technological systems, housing varied equipments and a long high performance computer infrastructure. Additionally, this system tends to be highly dynamic due to a high unpredictable variable workload that increases the complexity level. The resulted intrinsic complexity makes them difficult to manage and maintain over time. Since technology is able to offer new capabilities, it is necessary to design new resource management models that take these new technology characteristics into account. Multi Agent Systems (MAS) theory [10] can provide a new root for managing Cloud systems based on the distribution of responsibilities, flexibility, and autonomy. In fact, agents, thanks to their capability of both executing in a proactive, reactive way to environment changes, can naturally deal with dynamism, and unpredictability [7]. The Cloud computing based agent new discipline is an effective method to deal with complexity and dynamic issues of Cloud computing and their elastic behavior, in terms of a series of agents that are autonomous in behaviors, and capable of advanced social interactions (cooperation, coordination, negotiation) with each other to carry out actions needed to achieve specific goals (Elastic global behavior emergence) [7]. Moreover, managing the functions of the nucleus of Cloud computing system through an agent-based model allows the resulting platforms to be much more efficient, scalable and adaptable than they currently are.

Multi Agent System [10] has shown an excellent way for analyzing, designing and implementing variety of complex distributed software systems, from small systems such as Smart Web Services to large critical systems such as Air-traffic Control. However, the basics diversity, on one hand, and the complexity of concepts related to agents, on the other hand, makes it difficult to conceive and develop. The usage of formal methods characterized by their efficiency, precision, and reliability constitute a complementary approach that would offer considerable flexibility and expressiveness to rigorously specify MAS at both structural and behavioral levels. In addition, they provide an early integration of verification at the design process. BRS is a formal model introduced by Milner [11] for modeling ubiquitous, distributed computing systems. BRS have shown their adequacy in several domains, such as: Biological Systems [12], System of Systems [13], Context aware Systems [14], Cloud Computing [15], etc. Recently, many works have investigated the usage of BRS as semantic formal framework to modeling and verifying Multi Agent System [16,17]. Those propositions have shown their effectiveness and ability to perfectly specify the MAS at both structural and behavioral aspects with a verification of some system properties on the resulted specification.

In this work, our main contribution is to propose an automatic intelligent Cloud of Clouds Elasticity Management System that considers the elasticity management at both Micro (Intra Cloud) and Macro (Inter Cloud) levels, envisaging Cloud elastic behavior ensuring even in system critical situations. Our development methodology is described in Fig. 1. Principally, we focus on two main steps:

- Firstly, we exploit Multi Agent System (MAS) as an effective formalism to reduce the complexity of modeling and analyzing Cloud system elasticity. The first step defines a bridge or an intermediary semiformal version (*MAS-C2EM*) that prepares the passage to the formal one.
  1. We adopt a process designing a set of roles and agents interaction, which help us to construct a more hierarchical, structural advanced Multi Agent System for Cloud of Clouds Elasticity (*MAS-C2EM*) model.
  2. As a focus, we detail Top Clouds Cooperation based on Fuzzy Dominance mechanism, proposed in the context of Inter Cloud elasticity strategy execution.
- Secondly, we adopt Bigraphical Reactive System (BRS) as a semantic formalism to specify MAS structural and behavioral aspects. More precisely:
  1. We extend our previous solution [18] that focused on the structural part by reaction rules definition modeling the cooperative *MAS-C2EM* behavior.
  2. In order to verify proposition correctness, we use the Model Checker BigMC [19] tool to validate the Bigraphical Multi Agent System for Cloud of Clouds Elasticity Management (*BigMAS-C2EM*) ability to reach Cloud elastic behavior.

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