iNet: A Biologically-inspired Adaptation Mechanism for Autonomic Grids

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Abstract

This paper describes a biologically-inspired adaptation mechanism that allows grid services to autonomously adapt to dynamic environment changes in the network. Based on the observation that the immune system has elegantly achieved autonomous adaptation, the proposed mechanism, the iNet artificial immune system, is designed after the mechanisms behind how the immune system detects antigens (e.g. viruses) and specifically reacts to them. iNet models an environment condition (e.g. network traffic and resource availability) as an antigen, and a behavior of grid services (e.g. migration and replication) as an antibody. iNet allows each grid service to (1) autonomously sense the current environment conditions (i.e. antigens) and (2) adaptively perform a behavior (i.e. antibody) suitable for the conditions (i.e. antigens). Empirical experiment results show that iNet works efficiently at small memory footprint, and it makes grid services adaptive to dynamic environment changes.

1. Introduction

Grid systems are expected to be more autonomous and adaptive to dynamic environment changes in the network (e.g. changes in network traffic and resource availability) in order to improve user experience, expand application's operational longevity and reduce maintenance cost. As inspiration for a new paradigm for grid services, the authors of the paper observe that various biological systems have already developed the mechanisms necessary to achieve autonomy and adaptability.

The NetSphere architecture applies key biological concepts and mechanisms to design grid services. It implements each grid service as a group of distributed and autonomous software agents. This is analogous to a bee colony (grid service) consisting of multiple bees (agents). Each agent implements a functional service and follows biological behaviors such as replication, migration, energy exchange, pheromone emission and death.

This paper addresses autonomous adaptability of grid services. The proposed adaptation mechanism, iNet, is designed after the mechanisms behind how the immune system detects antigens and produces specific antibodies to kill them. iNet models an environment condition (e.g. network traffic and resource availability) as an antigen and a behavior of agents as an antibody. iNet allows each agent to autonomously sense its local environment conditions (i.e. antigens) to evaluate whether it adapts well to the sensed conditions, and if it does not, adaptively perform a behavior (i.e. antibody) suitable for the conditions (i.e. antigens). For example, agents may invoke migration behavior for moving towards network nodes that accept a large number of user requests for their services. This leads to the adaptation of agent locations, and agents can reduce response time for users.

2. NetSphere architecture

In the NetSphere architecture, agents are designed based on the three principles described below.

Decentralization**:** Agents are decentralized. There are no central entities to control and coordinate agents (i.e. no directory servers and no resource managers). Decentralization allows agents to be scalable and simple by avoiding a single point of performance bottleneck and any central coordination in deploying them.

Autonomy**:** Agents are autonomous. They autonomously behave and interact with each other without any from/to other agents and platforms.

Adaptability**:** Agents are adaptive to changing environment conditions (e.g. user demands, user locations and resource availability). Each agent contains iNet, which allows the agent to adaptively behave against the current environment conditions.

In the NetSphere architecture, each agent is implemented as a Java object and runs on a NetSphere platform. It is a middleware platform implemented in Java, and each platform runs atop a Java virtual machine on a network host. Each agent consists of three parts: attributes, body and behaviors. Attributes carry descriptive information regarding the agent, such as agent ID and description of a service it provides. Body implements a service the agent provides. For example, an agent may implement a genetic algorithm for an optimization problem, while another one may implement a physical model for scientific simulations. Behaviors implement non-service related actions that are inherent to all agents. Currently, agents support communication, migration, replication, death, energy exchange and environment sensing behaviors.

3. The iNet artificial immune system

The immune System is an adaptive defense mechanism to regulate the body against dynamic environment changes (e.g. antigen invasions). Involving a number of interactions among various white blood cells (e.g. lymphocytes) and molecules (e.g. antibodies), it evokes two immune responses: *innate* and *adaptive responses*.

In the innate response, the immune system performs self/non-self discrimination, which detects antigens (non-self foreign cells). The detectors for self/non-self discrimination, called T-cells, are produced and trained through the negative selection process in thymus. In this process, thymus removes T-cells that react with the body's own cells (self cells). The remaining T-cells are used as detectors for non-self cells. When T-cells detect non-self cells, they secrete chemical signals to activate the second immune response.

The second immune response, called adaptive immune response, produces antibodies that specifically react and eliminate an antigen identified by T-cells. In this process, antibodies are prioritized to determine which ones react with the antigen more strongly than which ones.

Following how the immune system works, iNet consists of the environment evaluation facility and behavior selection facility, which implements the innate immune response and adaptive immune response, respectively. The environment evaluation facility performs two steps: initialization and self/non-self classification. The initialization step randomly generates feature vectors first, each of which consists of features that represent environment conditions. Then, like the negative selection in the immune system, the initialization step removes the feature vectors that closely match with the (self) environment conditions, where agents do not have to behave for adaptation. This is performed via vector matching between randomly generated feature vectors and (self) feature vectors that human users supply. Similar to T-cells, the remaining feature vectors are used to detect non-self environment conditions (i.e. antigens), where agents need to behave for adaptation.

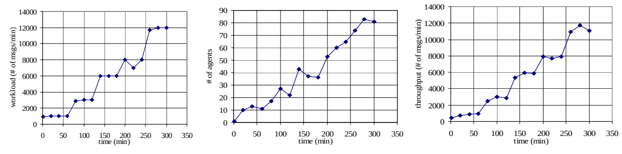
The second step in the environment evaluation facility implements self/non-self discrimination in the immune system. It uses the feature vectors created in the initialization step (i.e. artificial T-cells) to classify the current environment condition into self or non-self; whether an agent needs to invoke a behavior for adaptation or not. This classification step is performed with a decision tree built from feature vectors. Once the current environment condition is classified as non-self, the environment evaluation facility activates the behavior selection facility.

The behavior selection facility selects an antibody (i.e. agent behavior) suitable for the non-self environment condition identified by the environment evaluation facility. The behavior selection facility consists of a network of antibodies (agent behavior). They are linked with each other with stimulation and suppression relationships. Each antibody has its own concentration value corresponding to the number of the antibody. Concentration value is used as priority in behavior selection. Behaviors (antibodies) are linked with each other using stimulation and suppression relationships. When an environment changes (i.e. when an antigen is reported by the environment facility), the behavior selection engine identifies candidate behaviors suitable for the current environment condition, prioritizes them based on their concentrations, and then selects the most suited behavior (an antibody) from the candidate behaviors. When prioritizing behaviors, stimulation relationship between behaviors contributes to increase the concentration value, and suppression relationship contributes to decrease it. Each relationship has its own strength. The relationship strength indicates the degree of stimulation or suppression.

4. Empirical measurement results

Several empirical experiments were carried out to evaluate the efficiency of iNet and the adaptability of grid services developed with iNet. Experimental results show that iNet efficiently classify a current environment condition and select a suitable behavior for the environment. They show no critical latencies in iNet performance.

The adaptability experiment was conducted with agents implementing web services. They run on 16 NetSphere platforms deployed on eight PCs that are connected with each other based on a grid topology. (1) shows the workload (i.e. number of service requests) generated to web service agents. (2) shows how the number of agents changes against the workload change. As agents replicate in response to higher workload, they autonomously change their population. (3) shows how many response messages agents send back to users. Since agents migrate to platforms where resource availability is higher, they change their locations so that they process service requests more efficiently.



(1) generated workload, (2) # of agents, (3) throughput of agents.