Design and Implementation of a Bio-Inspired System Platform

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***Abstract*-Bio-Inspired systems are widely being developed today and have become a focus of attention as an efficient system model for large-scale network application services. However, there are difficulties associated with implementation according to the model properties such as scalability, adaptability and survivability. In order to resolve such problems, this paper proposes designing a multi-intelligent mobile agent referred to as Ecogent as well as a platform that allows the Ecogent to provide services to address the three properties of the ecosystem. The Bio-Inspired model platform is designed and implemented based on two sub-platforms. One is the ERS (Ecogent Runtime Services) platform that provides basic functions of a mobile agent including registration, life cycle, migration, communication, location and fault tolerance. The other is the Bio platform that provides the capability of evolution and adaptability through genetic algorithm and stigmergy controls. Ecogent equipped with survivability and autonomy along with a simple platform structure modularized for flexibility and scalability facilitate development of various Bio-Inspired system model applications. By implementing several model applications of the ecosystem using the Bio-Inspired platform, it was shown that various types of application system could be easily developed.**

I. INTRODUCTION

With the rapid development of the Internet, network-based application services that link numerous network nodes around the world are expected to be constituted of mainstream application services. The Bio-Inspired computing model [1] was introduced as a solution for the application/system software that operates in such large-scale systems. In practical terms, however, it is usually difficult to develop applications based on such models. Due to the diverse nature of the application fields and the vastness of the ecosystem, the idea of imitating it is a tremendous challenge. Accordingly, there was a need to develop a Bio-Inspired system platform that satisfies the properties of the ecosystem such as scalability, adaptability and survivability while facilitating the development of various applications.

In order to implement such a platform, an intelligent agent must be developed as in the case of ants that resolve problems based on spontaneous organization. There is also the need to design a platform capable of controlling and managing the agent. The Bio-Inspired system imitates such properties of the ecosystem, and one of the representative models is the "Bionet Platform"[3] developed at UCI. The Bionet platform consists of small objects called "Cyber Entities (CE)" and supports simple and diverse behavior among the objects as well as efficiency, scalability, reusability, and simplicity based on spontaneous interactions among the objects. However, the platform fails to support survivability, which is one of the important features of the Bio-Inspired system.

Therefore, we developed a platform of Ecogent which is an intelligent multi-agent platform. Ecogent derived by combining "ecology" and "agent." The platform that implements the Bio-Inspired system through Ecogent services can be categorized into the ERS (Ecogent Runtime Services) platform and the Bio platform. The ERS platform provides numerous basic services such as registration, migration, communication and fault tolerance of Ecogent. The Bio platform provides evolution and stigmergy control functions using the ERS platform.

Diverse model applications of the ecosystem were developed using the Bio-Inspired platform implemented for this study, and it was confirmed as a result that the proposed approach facilitated the system development process and substantially improved the performance of the system.

II. PLATFORM DESIGN FOR THE BIO-INSPIRED SYSTEM

In order to develop various application programs using the Bio-Inspired system, it is necessary to design a platform that provides common services that can be utilized by each application program and supports the properties of the ecosystem. Accordingly, an intelligent agent must be developed first, followed by the designing of a platform capable of managing the services among the agents.

The Bio-Inspired platform is divided into two sub-platforms of the ERS and the Bio platform, as shown in "Fig. 1." The ERS platform is responsible for various services including registration, migration and communication of the Ecogents, while the Bio platform performs functions such as evolution and stigmergy using the ERS platform. The application could be programmed by creating a lot of Ecogents that are evolving and cooperation each other using the service provided by ERS platform and BIO platform.

A. Design of Ecogent

1) Ecogent States: Ants and bees perform continuous labor for their colonies from birth to death. They move to other locations to find food, but during a time of crisis, they cease all work and fight against the intruders to protect their colonies.

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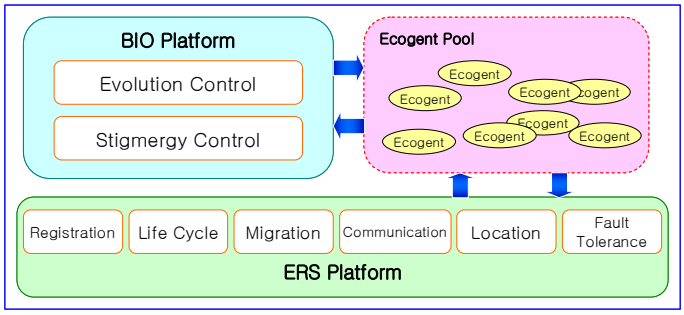

Figure 1. Bio-Inspired System Platform Structure

The Ecogent was designed by emulating such behaviors of ants and bees. When an Ecogent is created, it is registered into the system with the initial data (*Initiated*), and begins the activities according to its roles (*Active*). When there is another priority, an Ecogent must be able to pause its work (*Waiting*), and also have the capability to move between the platforms (*Transit*) like the ants and bees. Moreover, it is essential to have the ability to recover from a system error (*Suspend*) for survivability. In order to provide such functions, the Ecogent was designed with five states.

2) Execution of Ecogent: If an Ecogent is in the active state, it performs a sequential process of *monitoring, analysis, designing* and *execution*. An Ecogent first collects necessary information through the monitoring process. Then the gathered pheromone information is analyzed. During the design process, the Ecogent determines the tasks to be performed based on the analyzed data, stores the determined commands in the command queue, and carries out each command in the execution process. If the Ecogent concludes that there are no more tasks to perform for the monitor, analysis and design processes, it exits from the active state and becomes *terminated*.

B. *Design of ERS (Ecogent Runtime Services) Platform*

1) ERS Requirement Analysis

Scalability can be defined as the ability to cope with and resolve an increasing scale of a problem in executing a task [5, 6]. When the number of individuals increases for a certain area, the efficiency must be evaluated according to the relative execution. Therefore, *communication* and *migration* functions are required to provide such services. Transfer of information is made possible by communication among the individuals, and the information allows duplication of and migration among the individuals.

▪ Adaptability Analysis and Application

An organization in the ecosystem maintains a stable number of individuals and creates individuals that quickly adapt to the changing environment without artificial development or maintenance costs. An individual with a high degree of usage is capable of duplicating itself and generating a new individual with identical talents. In order to do so, the individual must have a high level of stored energy. On the other hand, if there is little requirement for a particular individual and the energy level reaches 0, the individual perishes. In turn, the *location* service is necessary for indicating where the high and low energy levels are. The *migration* service is also needed for helping the individuals roam around.

▪ Survivability Analysis and Application

An individual behaves in a certain manner in order to acquire more energy than other individuals, which ultimately reflects the urge of an individual to survive longer than another and increase the number of similar individuals. This implies that a useful and efficient individual has a higher probability of survival. In order to increase survivability, each individual must store duplicate of itself, and the *fault-tolerance* service is necessary to recover itself in case of an error.

2) Design for each ERS Platform Service

▪ Registration: Registers each individual Ecogent to the corresponding platform and endpoint, and receives a unique ID from the endpoint.

▪ Life Cycle: Creates and terminates an Ecogent from a higher hierarchy that uses the Ecogent as well as transforms the state of an Ecogent according to its objective.

▪ Migration: Transfers codes and data to the next platform according to Ecogent requests.

▪ Communication: Delivers messages among the Ecogents using ACL messages. For internal communication, endpoint is used as a lower hierarchy of the ERS.

▪ Location: Seeks other ERS platforms and necessary information using the registration service of a local platform.

▪ Fault Tolerance: Regularly updates the Ecogent state and creates Ecogent duplicates in order to provide fault-tolerance.

C. *Design of Bio Platform*

The Bio platform emulates properties of evolution and information delivery capabilities of the ecosystem.

1) Evolution Control: Evolution control manages evolution and adaptability of the parameters that determine the properties and execution methods of Ecogents under the distributed environment based on the genetic algorithm. With an objective of encoding diverse types of parameters and applying genetic operators according to the circumstances, a *genetic optimizer* class acting as a hub capable of linking every component was designed. The class was developed to select the genetic operator required for each problem such as reproduction with a desired type of chromosome, selection, crossover and mutation to perform a genetic algorithm.

2) Stigmergy Control: An ant leaves trails of pheromone as it moves in order to inform fellow individuals of the locations of food and shelter. Likewise, an Ecogent roams around the platform and leaves pheromone in order to share information with other Ecogents.

"Fig. 2" shows the stigmergy [2] control operation utilizing the ant colony algorithm. When an Ecogent moves around the platform to perform its tasks, it stores its data in the pheromone

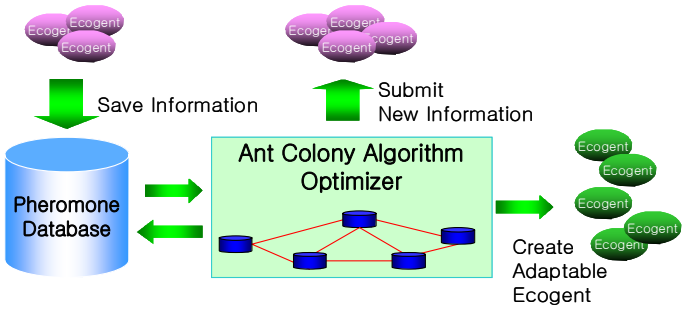

Figure 2. Ecogent Information Processing through Stigmergy Control under Distributed Network Environment

database of each local platform. The Ecogent applies the information to the ant colony algorithm using the message information it possesses or has accumulated in the database. Such highly adaptable Ecogents with information generated from the ant colony algorithm can be deployed in applications or platforms.

III. Implementation and Analysis of Bio-Inspired Platform

A. Implementation of Bio-Inspired Platform

The Bio-Inspired platform introduced in this paper was implemented using C/C++ as a set of classes. Let us show how to implement the Ecogent, ERS and Bio platform in more details.

1) Implementation of Ecogent: As shown in Table I, an Ecogent consists of data structure such as the Ecogent ID, states, platform information and replication ID for fault-tolerance, as well as methods such as monitoring, analyzing and planning. The data structure to fault-tolerance for each Ecogent allows easy system recovery during an error occurrence by retrieving the backup data. The Ecogent was designed with a simple structure to increase flexibility and usability.

2) Implementation of ERS Platform: The service platform manages the services by loading the service module, creating a new instance and enabling the Ecogent to access the service. Every service manages its instances according to the service platform. After the ERS platform was implemented, an experiment was conducted to evaluate the average access time to API for each service. Table II shows the average time for each service of the ERS platform in milliseconds. The experiment was conducted using Intel Pentium III PCs with 512MB RAM running RedHat Linux 9.0. 100Mbps Ethernet was used for communication among the PCs. As can be seen from the Table II, bottlenecks were found in migration, communication and location services. This is due to the fact that the endpoint function is used for network communication among the individuals.

Table I
ECOGENT STRUCTURE

```
class CEcogent : public cObject{
protected:
    string          ecogentID;
    int             state, replication_id;
    serviceTable    service;
public:
    virtual void    Monitoring();
    virtual void    Analyzing();
    virtual void    Planning();
};
```

TABLE II
AVERAGE API ACCESS TIME FOR EACH SERVICE

ERS service	Access time	ERS service	Access time
Registration	4 (ms)	Communication	200 (ms)
Life Cycle	60 (ms)	Location	172 (ms)
Migration	275 (ms)	Fault Tolerance	20 (ms)

3) Implementation of Bio Platform

GeneticOptimizer is the essential class of evolution control. This was done in order to select the desired forms of chromosome and genetic operators to perform genetic algorithms. When a chromosome with the highest level of adaptability is extracted by a general genetic algorithm, the existing Ecogent evolves into a different Ecogent adapted to the new environment. Stigmergy control was implemented by storing an item into or retrieving an item from the pheromone database. When an Ecogent carries out tasks while moving from one platform to another, it stores its data in the pheromone database of each local platform. The Ecogent then applies the message information it possesses or has accumulated in the database to the ant colony algorithm.

B. Test of Bio-Inspired Platform for Application Service

1) Load Balancing System: Using the Bio-Inspired platform, a load balancing system [4] was developed to distribute the load of a server used for e-training over the Internet. This application program can be easily implemented using stigmergy control of the Bio-Inspired platform. Each Ecogent maintains a routing table for determining the candidate for the next hop. Each router contains an ERS platform, and Ecogents move around the router leaving information about the neighboring routers. If an Ecogent leaves the information regarding the load level of a node it has passed in the routing table in the form of pheromone, the data provides the node direction of transfer when there is an overload at the server, enabling efficient load distribution under such circumstances. “Fig. 3” shows the standard deviation for overload distribution. It can be determined from the graph that the Eco-LB using the bio-inspired platform displays a better load distribution capability than the diffusion approach using the sequential diffusion algorithm [7], which has been proven to yield optimal convergence.

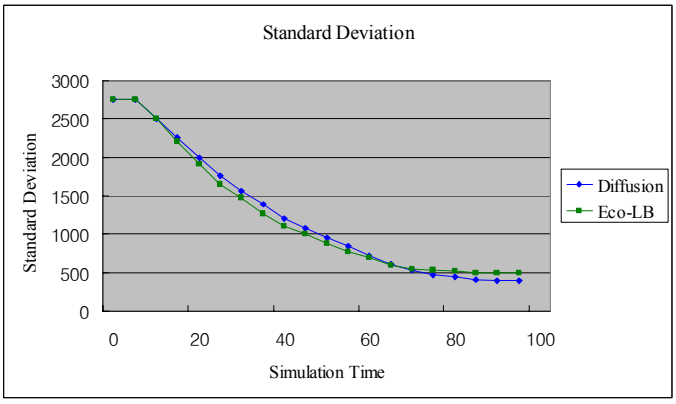

Figure 3. Load Distribution in Overloaded Network

2) Development of Intrusion Detection System: The Bio-Inspired platform is capable of developing an intrusion detection system [4] using the genetic optimizer class of the Bio platform. The genetic optimizer pertinently converts the results obtained during the learning process of various intrusions patterns. The converted Ecogents are distributed throughout the system via the migration service of the ERS platform to implement a system capable of detecting various types of intrusion. Even when the system is intruded upon and some Ecogents are damaged, the fault-tolerance function of the ERS platform will be activated to quickly recover the damaged Ecogents. The experiments were conducted for the general system where the genetic algorithm was not applied (Normal), and the system for which the genetic algorithm and the migration system were deployed (Ecogent). Two of the well-known algorithms for machine learning, Naïve Bayes [5] and Decision Tree algorithms [6] were used as the main system algorithm. Table III indicates that implementing the distribution genetic algorithm using the Ecogent migration service displays better performance than the general system without the genetic algorithm.

IV. Comparisons with Other Related Studies

The Bio-Inspired platform implemented in this paper is compared with the Bionet platform [3] developed by UCI to explain the properties of the ERS and Bio platforms. The Cyber Entity (CE) on the Bionet Platform is a non-centralized platform with a good scalability, adaptability and without a system bottleneck. However, the CE does not provide survivability based on the fault-tolerance function, making Ecogent a more advanced type of a mobile agent. As shown in Table IV, the Bionet Platform contains all services and functions in a single platform. Furthermore, Java implementation used in CE implementation results in a heavy platform. In comparison, the modularized structure of the Bio-Inspired platform offers convenience and flexibility in a light and fast platform based on the C/C++ implementation.

TABLE III
DETECTION ACCURACY FOR EACH ALGORITHM OF INTRUSION DETECTION SYSTEM

	Naïve Bayes IDS [5]		Decision tree IDS [6]	
Algorithm	Normal	Ecogent	Normal	Ecogent
Search precision	92.38	95.87	93.09	93.91
Standard deviation	1.36	0.96	1.14	1.11

TABLE IV
COMPARISON OF ERS AND BIONET PLATFORM SERVICES

	ERS platform	Bionet platform
Similar services	1. Migration 2. Communication 3. Life cycle 4. Location 5. Stigmergy control 6. Evolution control	1. Migration 2. Communication 3. Lifecycle regulation 4. Discovery 5. Pheromone emission 6. Environment sensing
Unique services	1. Registration 2. Fault tolerance	1. Energy exchange and storage 2. Relationship maintenance

V. Conclusions

This paper presented the development of a Bio-Inspired platform to facilitate the design of various application programs of the Bio-Inspired system model. In order to do so, the Ecogent was developed as a multi-intelligent mobile agent with autonomy and survivability. Furthermore, in order to develop applications based on the Bio-Inspired calculation model, the Bio-Inspired model platform was designed with two sub-platforms. The ERS platform provides basic mobile agent functions including registration, life cycle, migration, communication, location and fault tolerance. The Bio Platform offers the evolution ability and adaptability through Evolution Control and Stigmergy Control. The simple and modular platform structure designed for flexibility and scalability facilitates the development of various Bio-Inspired system model applications. In practice, diverse model applications of the ecosystem were developed using the Bio-Inspired platform, and it was confirmed that the proposed approach facilitated the system development process.

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