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Jack-in-the-Net: Adaptive Networking Architecture for Service Emergence

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SUMMARY In this paper, we propose a radically new paradigm of the adaptive networking architecture for service emergence: **Jack–in–the–Net (Ja–Net)**. In the proposed architecture, services are implemented by a collection of multiple entities called cyber-entities. These cyber-entities have functionality related to their service and follow simple behavior rules (e.g., migration, reproduction, energy exchange, mutation, death) similar to biological entities. In Ja–Net, useful emergent services and behaviors (e.g., scalability, adaptation, evolution, security, survivability, and simplicity) result when individual cyber-entities interact.

key words: *distributed computing, multi agent, self-organizing, service emergence, natural selection, evolution, adaptation*

1. Introduction

We envision a future where a universal network openly connects every human being and most human-made electronic objects. In addition to conventional computing devices, new devices such as sensors, wearable computers, mobile phones, vehicles, appliances, tools, and even unmanned robotic devices in space are nodes in the universal network. Thus, the universal network spans locations engaged in every human endeavor, including the home, workplace, cars, trains, airplanes, train stations, airports, and space. The universal network also supports various types of information that diverse devices collect (ranging from the temperature of the refrigerator to user personal information), creating a complex web of information.

The universal network is viewed as an extension of every single person and organization. The wide availability of open computing resources (openly shared CPU, memory, and bandwidth) and natural interfaces (e.g., speech recognition and brain-computer interfaces) allows the user to merge with the network into a unified entity, giving the person a ubiquitous presence. This unified entity (1) extends the user's identity and presence beyond his or her immediate physical surroundings, (2) extends the user's domain of control beyond his or her physical surroundings, and (3) extends the user's mental capacity beyond human memory and computational abilities.

The unified entity extends a user's identity and presence beyond his or her immediate physical surroundings by maintaining and making available to authorized parties personal information such as medical information, social security number, financial information, personal preferences, and current physical location. Such a network would, for example, monitor user's health conditions and allow doctors to instantly access personal medical information when medical attention is necessary. It would monitor user preference and allow hotel and airline reservations to be made without specifying preferences (non-smoking, etc.) every time.

The unified entity extends a user's domain of control beyond his or her immediate physical surroundings by allowing immediate control of all devices belonging to the unified entity. For example, a person could be in an airplane and activate the home DVD recorder to record an interesting program that the person just discovered from a friend.

The unified entity extends the user's mental capacity beyond normal human memory and computational abilities by utilizing any available computing resources in the network. Such computing resources provide services such as personal information management (e.g., calendar, address books), finance (banking, electronic commerce), communication (e.g., video conferencing, collaborative applications), and entertainment (e.g., multi-player games, movies).

In order to realize the vision described above, we propose a radically new paradigm of the the adaptive networking architecture for service emergence: **Jack–in–the–Net (Ja–Net)** [1][2]. Key design principles behind this new architecture are autonomous entities (called cyber-entities) and emergence of service created from such autonomous cyber-entities.

In Ja–Net, major components are represented by cyber-entities to reflect the fact that the universal network described earlier consists of a number of components. For instance, various devices, as well as users, on the universal network are components. Services on the universal network may consist of finer granularity service components. Each piece of information on the universal network is a component.

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The cyber-entities in Ja–Net are autonomous and self-organizing. Cyber-entities also sense and monitor the dynamically changing environment, autonomously behave and adjust their behavior and evolve to allow flexibility and adaptability of service. This is because that the scale and highly dynamic nature of the universal network prohibits human management of cyber-entities. We envision that the universal network to span wide geographical areas, supporting a large number of users and various types of devices. The universal network is highly dynamic, where user preference and usage patterns, as well as network conditions, change dynamically.

In the proposed Ja–Net, cyber-entities follow simple behavior rules similar to biological entities. They autonomously interact with each other to dynamically create a new service, and provide service. Desirable behaviors and characteristics emerge in the service from the collective actions and interactions of its cyber-entities.

2. Service Examples

In Ja–Net, a service is provided by a group of cyber-entities. Each cyber-entity in the Ja–Net has service functionality related to the service and follows a set of simple behavior rules. Some examples of services that the Ja–Net can enable include the following.

Example 1: Personalized Service
In this example, cyber-entities monitor user preference and usage patterns. For instance, suppose the following interaction sequence in a house. A cyber-entity providing sensory information service (sensor cyber-entity in short) detects the door's opening and broadcasts a signal. A video camera cyber-entity picks up the signal and record a moving object, sending the image to an image analyzer cyber-entity. The image analyzer cyber-entity performs image recognition process and broadcasts that the moving object is the mother of the house. Then, a stereo cyber-entity in the living room picks up the message and starts playing a rock music (through an interaction between a stereo and a rock music cyber-entities). The mother, however, hates rock and turns off the stereo. After repeating this process for a few times, the stereo cyber-entity learns the mother hates rock music and starts playing Latin music. If the mother likes the music, the stereo keep playing Latin music whenever the mother comes back home.

Example 2: Coordination of Small Devices
In this example, we assume that a large number of sensor devices scattered over a wide geographical area. Assume these sensor devices support cyber-entities. Sensor devices (i.e., cyber-entities on sensor devices) monitor other sensor activities (such as what sensor data are being transmitting) and the environmental conditions

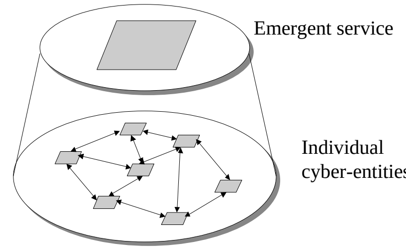

Fig. 1 Emergence of service

(such as the density of nearby sensor devices). Sensor devices, based on monitoring results, adjust their sensing behaviors (i.e., what to sense, how often to sense, where to move to and sense, if they have movement capabilities, etc.) so that a group of sensor devices collectively self-organize and perform one sensor task.

3. Overview of the Ja–Net

3.1 Architecture Overview

In Ja–Net, a service is implemented by a group of distributed, autonomous entities called cyber-entities (see Figure 1). Each cyber-entity has basic functionality related to their service and follows a set of simple behavior rules. When a user requires a service, a cyber-entity which represents the user creates a service request and sends it to the cyber-entities within its environment. (The environment of a cyber-entity refers to the area where the cyber-entity can communicate with other cyber-entities in the area.) Cyber-entities that are members of the service receive the request and collectively provide the requested service.

A service built using the Ja–Net varies depending on which cyber-entities contribute to the service and its surrounding environment. The network may contain many services, each with their own group of individual cyber-entities. Services may be manually created. They may also emerge spontaneously through the interaction of cyber-entities. For instance, cyber-entities may create a relationship with nearby cyber-entities providing a similar or complementary service to form a service. Desirable behaviors and functionality emerge in the service from the autonomous and local actions and interactions of the cyber-entities. Services go through the natural selection process so that only successful ones survive while unsuccessful one are eliminated from the network.

In addition to emergence based on autonomous local behavior of simple cyber-entities, the Ja–Net adopts the following key concepts.

Energy as a natural selection mechanism: Each cyber-entity may store and expend energy for living. Cyber-entities may gain energy in exchange for performing a service, and they may pay energy to use network and computing resources. Thus, energy may also be viewed as a unit of exchange similar to money in economic systems. The abundance or scarcity of stored energy may affect cyber-entity behaviors and contributes to the natural selection process of the Ja–Net. For example, an abundance of stored energy is an indication of higher demand for the cyber-entity; thus the cyber-entity may be designed to favor reproduction in response to higher levels of stored energy. If the energy expenditure of a cyber-entity is not balanced by the energy units it receives from providing services to other cyber-entities (i.e., indicating lack of demand), it will not be able to pay for the network resources it needs, i.e., it dies from lack of energy or starvation. Cyber-entities with wasteful behaviors (replicating or migrating too often) will have a higher chance of dying from lack of energy.

Diversity: A sufficient degree of diversity is provided at the cyber-entity level in the Ja–Net. We design multiple cyber-entities with different behaviors to perform the same task to ensure sufficient degree of diversity. Diversity is important to ensure that the evolution process is given a large enough domain of behavioral factors and resulting services on which to perform natural selection so that the system adapts and evolves to suit a wide variety of environmental conditions [5].

The above concepts are implemented using relatively simple cyber-entity behaviors. Due to space limitations, only a small number of cyber-entity behaviors are listed below. Note that some cyber-entities may not have all the behaviors listed below.

Energy exchange and storage: As explained above, cyber-entities may receive and store energy for providing services to other cyber-entities. They also expend energy for using network resources.

Establishing relationships: Cyber-entities may form affiliations or groups by establishing relationships with a number of other cyber-entities. There are various kinds of relationships. Different relationships may cause different interactions. For example, cyber-entities providing the same service may establish relationships to serve as back-up to each other. Cyber-entities providing complementary services may establish relationships for cooperation. Cyber-entities with common attributes may establish relationships to form a community. (Relationship may also be created based on who created or owns cyber-entities and who use cyber-entities.) Cyber-entities with relationship to each other can communicate. Cyber-entities develop new behavioral algorithms to create relationships through mutation and crossover.

Sensing the environment: The environment of a cyber-entity includes all cyber-entities that it has a relationship with (namely, cyber-entities that it can communicate with) and the network resources that it can access (such as communication links, nodes and routers, CPU and buffer resources). In Ja–Net, cyber-entities

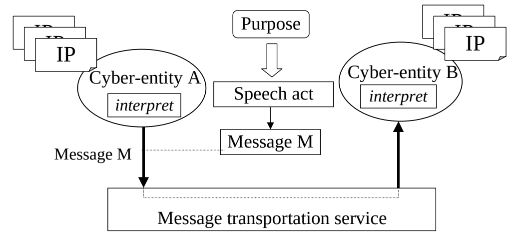

Fig. 2 Inter-CE Interaction

monitor their environments. A cyber-entity may also monitor to obtain information such as user information (e.g., user preference, user behavior/usage patterns) and network resource information (e.g., network topology, communication link bandwidth, CPU processing power of network nodes). Note that not all the cyber-entities may exist in the environment; for a given cyber-entity, its environment only includes those cyber-entities that it has a relationship with. Note also that environments are different for different cyber-entities.

Interaction: As shown in Figure 2, cyber-entities interact with each other for some purpose. They use high-level, Speech act [3][4]-based language like ACL (Agent Communication Language) to enable flexible interaction. There, each cyber-entity defines one or more interaction protocols (IPs) which specifies a sequence of local actions and conversation with other cyber-entities. Note that in Ja-Net, an IP is not global among cyber-entities but it is locally defined by each cyber-entity. Therefore, it is necessary for two cyber-entities to resolve which IPs to use for their conversation before they start a new conversation. Each cyber-entity autonomously interacts with "appropriate" cyber-entities in the environment by selecting one or more cyber-entities among its environment. There are different policies on how to select "appropriate" cyber-entity to interact with. For instance, a cyber-entity may select a cyber-entity that it has most recently interacted with.

Migration: Cyber-entities may migrate from network node to network node .

Replication and reproduction: Cyber-entities may make a copy of themselves (replication). Two parent cyber-entities may reproduce and create a child cyber-entity (reproduction), possibly with mutation and crossover changes in the child's behavior and relationship with other cyber-entities.

Death: Cyber-entities may die because of, for instance, old age or lack of energy.

3.2 Service Emergence based on Strong Relationships

In Ja–Net, cyber-entities establish relationships with other cyber-entities for useful interactions and record necessary information about the partner in the relationship. Such information includes: attribute of the partner cyber-entity such as ID, age, energy-level, etc., service description of the partner, available interaction

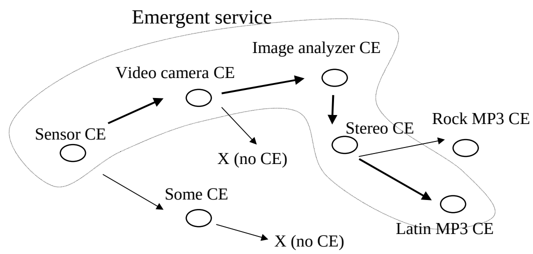

Fig. 3 An exapmple of service emergence

protocols (IPs), and strength of relationship. An emergent service results when relationships between a collection of cyber-entities which provide an end service become strong enough to form a group. Once a group is formed, service information (service name, service description, etc.) is created and advertised to users. Users, then, can request for a service by the service information.

In Ja–Net, useful partner cyber-entities are distinguished by the strength of relationships. The utility degree of the partner is evaluated for each interaction based on which strength value is calculated. There are various ways to evaluate the utility of cyber-entities. For instance, a cyber-entity may rate cyber-entities in terms of its utility according to the amount of energy paid for its service. When a collection of cyber-entities provided a service to a user, the user can also give a feedback by indicating the user's satisfactory degree to the service. Feedbacks from users are propagated to all cyber-entities which provided the service, and the strength of relationships are modified based on the satisfactory degree of the user: if it's high, the strength is strengthened otherwise weakened. Thus, the strength of relationships is modified by reflecting user preference.

Figure 3 shows a process of service emergence for personalized service example described in section 2. A collection of cyber-entities from a sensor to a Latin MP3 are grouped together based on strong relationship. Since the mother hates rock music, the relationship between stereo cyber-entity and the rock MP3 cyber-entity are weakened. Instead, relationship between the stereo cyber-entity and the Latin MP3 cyber-entity are strengthened due to the mother's preference.

3.3 Characteristics of the Ja-Net

Services and applications built using Ja–Net will share a common set of important characteristics, namely scalability, adaptability, and evolution.

Scalability: Ja-Net is scalable in terms of number of cyber-entities and emergent services because all of its cyber-entities are designed to act autonomously and locally based on local information in their environments. There is no entity controlling all entities, creating no bottlenecks around a master cyber-entity when the number of cyber-entities grows. Cyber-entities repeat the same local actions and interactions in their environments even when the size and population of the service increases.

Adaptation: The super-entity adapts to heterogeneous and dynamic network conditions through the emergent behavior and relationship of its cyber-entities. For instance, cyber-entities can be designed to migrate toward the source of requests when the resource cost at the migration destination is less than a given threshold, while avoiding areas of the network where resource costs are high. Cyber-entities can be, at the same time, designed to replicate when demand is high (i.e., when its stored energy level is high), and to die when demand is low (i.e., when its stored energy level reaches zero).

Evolution: Services evolve in the Ja–Net through the creation of diversity (i.e. service emergence) and natural selection. Diverse services emerge through dynamically creating and modifying relationships. Diverse behaviors of cyber-entities (created through their replication/reproduction with mutations and crossovers to behavior algorithms) also contribute to the diversity of the service. Note that service diversity is created from the cyber-entity level diversity, and there is no service level mechanism for creating diversity in the Ja–Net. Natural selection on the Ja–Net is also at the cyber-entity level. An emergent service will dissapear and the service will not be provided any more when relationships between any two member cyber-entities are lost or any one of member cyber-entities dies due to lack of energy. Thus, natural selection is also performed at the cyber-entity level. Evolution of services promotes the adaptability of the system.

4. Conclusions

In this paper, the authors proposed a new architecture, Jack–in–the–Net (Ja–Net), where services are created from a group of autonomous cyber-entities. The authors are currently investigating various key research issues such as design of a simulation tool for the Ja–Net, design of a platform software that manages cyber-entities, design of a cyber-entity (e.g., behavior algorithms, service code).

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