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Invited Paper

Symbiotic Computing Based Approach Towards Reducing User's Burden Due to Information Explosion

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Abstract: In this work, Symbiotic Computing (SC) based solution to combat the problem of Information Explosion is addressed. Symbiotic Computing was proposed to bridge the gap between the Real Space (RS) and the Digital Space (DS) by creating symbiotic relations among users in the RS and the information resources such as software, data, etc. in the DS. SC is realized by adding a new axis, S/P computing (Social and Perceptual Computing), to the advanced ubiquitous computing consisting of ambient and web computing. Here, a new framework of SC based on Symbiotic Space (SS) and Symbiotic Space Platform (SSP) has been designed to construct and maintain Symbiotic Relations for S/P computing in order to reduce the burden of Information Explosion. Finally the feasibility of our proposal has been tested by bench-top simulation through applying logical model of Symbiotic Computing to a typical example of Information Explosion.

Keywords: symbiotic computing, social agent, symbiotic relation, information explosion

1. Introduction

The rapid growth of Information and Communication Technology (ICT) enables us to receive various kinds of information from the Internet by using high performance personal computers and recent advanced network technology. Ubiquitous computing technology can autonomously acquire awareness of the users and their surroundings from the explicit and implicit knowledge stored over the network. On the other hand, advanced web service computing supports web servers in the digital space in finding out the relation between the data input by users and those acquired by sensors in the real space and manage them as secondary data in the digital space. The various kinds of data are also analyzed by web service servers and the results are stored in the digital space as a higher level of knowledge.

In the digital space, day by day the quantity of data and information are increasing autonomously. People can easily send (store) and receive (use) enormous amount of information by using various communication media. This situation is called as Information Explosion or Info-Plosion [1]. The information explosion in the digital space is caused not only by the increasing quantity of information but also by the increasing diversity of users' needs according to their situation, social function and personality in the real space. As a result, a large amount of information in the digital space is left undefined regarding its utilization purpose. We do not know who will use the information for what purpose and when. The importance and quality of information is based on the user's personal interest as well as the user's background or social situation in the real space, which changes dynamically in general. These data and knowledge consist of a number of data components and have various kinds of aspects, features, values and usages from the users' points of view.

In this paper, 'Symbiotic Computing' is introduced to reduce the burden of Information Explosion. Symbiotic Space is proposed to build the flexible relations between the users in the Real Space and the information resources in the Digital Space based on Symbiotic Computing.

This paper consists of 6 sections. Section 2 presents an introduction of Symbiotic Computing. Symbiotic Computing comprises of Web Computing and Ambient Computing as well as S/P Computing, which denotes Social and Perceptual Computing. In Section 3, Symbiotic Space and Symbiotic Space Platform are introduced as the building blocks of Symbiotic Computing for implementation of S/P computing. Section 4 provides the concept of the agent-based model of Symbiotic Relations, especially how to realize S/P computing is covered in detail. In Section 5, the Symbiotic Computing model developed in the previous section is applied to the problem of Information Explosion to show the effectiveness of the model in reducing the burden of Information Explosion. It is seen that the model based on S/P computing can solve the problem successfully. The final section concludes the paper with discussion on future works and extensions.

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2. Symbiotic Computing and its Origin

2.1 The Concept of Symbiotic Computing

The basic concept of Symbiotic Computing (SC) [2] was proposed to bridge the gap between the Real Space (RS) and the Digital Space (DS) as a continuation of our research on Flexible Network [3], [4], [20], [21], [22], [23], [24]. Moreover we developed the model and the framework of Symbiotic Computing and prototyped some application systems based on the concept and the proposed model [6].

The concept of Symbiotic Computing was related to the calm computing proposed by Mark Weiser [14], [15] and the ambient computing [16], [17], [18], [19]. Ambient Computing paradigm has been devised to enhance Ubiquitous Computing that is spanned by Pervasive Computing and Mobile Computing as shown in **Fig. 1**.

Symbiotic Computing is realized to establish symbiotic relations between users in RS and information in DS, by creating a three dimensional computational space by adding a new axis S/P computing to the space spanned by the ambient computing and the web service computing as shown in **Fig. 2**. Here S/P computing, consists of Social Computing and Perceptual Computing, are explained as follows;

- Social Computing is a methodology for a computing system to recognize and reuse social activities and social relations between the users using social knowledge that is acquired by interaction with other users and mining from the Web services,
- Perceptual Computing is a methodology for a computing system to recognize user's intention and behavior in RS to help the user access assets in the Internet.

After proposing our concept of Symbiotic Computing, we also proposed a model and its applications. The agent-based framework of the applications consists of Personal Agent, Perceptual Functions and Social Functions that work over the ubiquitous infrastructure and the digital networks. The agent platform IDEA was developed for the symbiotic applications based on a Repository-oriented architecture [23], [24]. In this paper, we discuss the symbiotic computing-based solution to reduce Information Explosion which is imposing a tremendous burden to general users.

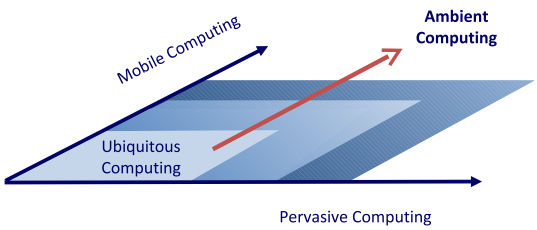

Fig. 1 Ubiquitous computing and ambient computing.

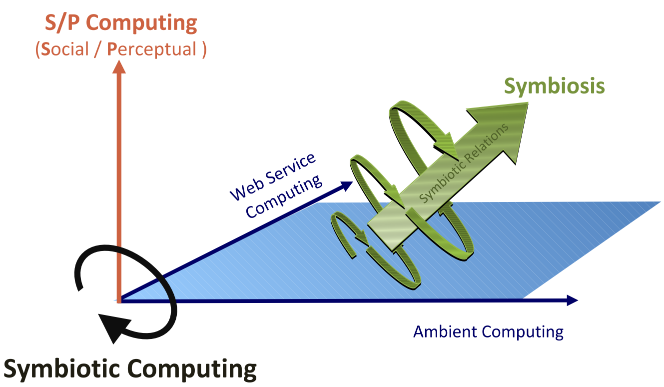

Fig. 2 The concept of symbiotic computing.

2.2 Why Symbiotic Computing?

Modern information systems have been designed and developed based on the criterion of efficiency. A user has to learn the system and make efforts to use it. That is, the user gets closer to the system. On the other hand, in order to overcome digital divide, sense of isolation, unease, distrust, etc., the system should get closer to a user. To realize such a system, we need another criterion "α" in addition to "efficiency" towards post-modern information systems. As the criteria α, we proposed "symbiosis" and Symbiotic Computing [2], [5], [9], [10], [11], [12], [13].

2.3 Brief History of Symbiotic Computing

Since early 1990s, we have been investigating the framework of Symbiotic Computing; its concept, model, design, and applications [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31]. We emphasized the importance of the concept of "Symbiosis" as a novel computing paradigm towards post-modern distributed computing model at IPSJ Workshop held in 1994 [2]. Furthermore, we proposed a concept of Symbiotic Computing to bridge the gap between the users and DS that were getting wider and wider day by day. To achieve the goal, we introduced a new concept of Flexible Computing in order to build a fundamental infrastructure for the Symbiotic Computing. During our project on Flexible Computing from 1994 to 2000 we designed models and architecture of the Flexible Network [3]. The project also developed various kind of Symbiotic-Computing-based applications such as symbiotic offices [5], [24], [25], [26], along with expanding Flexible Computing [8], and finally, the total concept was renamed Symbiotic Computing.

Here, examples of the gap between RS and DS are digital divide, sense of isolation, unease, distrust etc. For instance, digital divide implies that closer the people live to DS more the benefits they can get. In order to get closer and receive the services, they must know the architecture of the DS, how to access and how to act in DS. Without that, this can be a major concern.

Based on the above concept and model of Symbiotic Computing, we have been developing various kinds of application systems. Some of the applications are as follows:

(1) Flexible Network [3], [4], [8], [20], [21], [22], [23]
(2) Symbiotic Digital Office [24], [25], [26]
(3) Watch-Over Support System [27], [28]
(4) Health Care Support System [29], [30]

3. Symbiotic Space and Symbiotic Space Platform

In order to apply Symbiotic Computing to reduce the burden of Information Explosion, Symbiotic Space (SS) and Symbiotic

Space Platform (SSP) are proposed. The framework of Symbiotic Computing consisting of SS and SSP is presented in the following subsections.

3.1 Framework of Symbiotic Computing

SS and SSP are proposed to implement Symbiotic Computing as is shown in **Fig. 3**. The SS is an agent space based on the Symbiotic Computing in order to bridge the gap between RS and DS and it consists of Personal Agent Space (PAS) and Social Agents Space (SAS). The SSP is a platform to run the agents.

PA is a special agent that interacts with a specific user at any time and at any place through functions of Perceptual Computing that is a methodology for a computing system to recognize user's behavior and situation in RS. The PA observes behaviors, aspects, requests of the user, and saves information of the user's preference, motivation, social activity etc.

Meanwhile, an SA is an agent based on Social Computing which is a methodology for a computing system to recognize and reuse social activities that are saved in resources in DS in individual description form, such as group work, caring children. The SA observes specific data in DS according to the goals implemented in SA and saves meta-data about the data in DS. Our basic idea of applying Symbiotic Computing to Information Explosion is to introduce SS for making relationship between the PA acting for the user and the SA acting for the information provider autonomously. The relationship is called a symbiotic relation because the user and the provider of data satisfy each other in terms of utility function of game theory [34], [35] by keeping relation through the SS. The symbiotic relations are created and maintained by observing interactions between agents in SS autonomously.

SSP consists of Social Functions (SF) and Perceptual Functions (PF) that are developed using Social Computing and Perceptual Computing respectively. The SF observes interactions of all agents by continuously monitoring time series of message patterns, and transforms them into structured cognitive symbols based on a knowledge model that represent relations in a society of agents. While, the PF observes activities of users by monitoring signals received from the sensors embedded in RS, and transforms them into structured cognitive symbols based on a knowledge model to perceive user's utterance, motion, aspect, situation and so on.

In order to focus our discussion on Information Explosion in this paper we would like to address the design of SF mainly which has a strong relation to Social Computing, although we have been studying applications incorporating the PF running in the SSP [30], [31].

In the past, various kinds of functions concerning SF have been studied based on a paradigm that is rapidly growing within AI because of situated and interactive perspective [32] of the Agent-oriented Computing and Multi-Agent System [33]. For example, game theory was introduced into decision making functions of information systems [34], [35], and knowledge models were introduced into web intelligence [36], [37], [38] to recognize desired web pages for each person. Expanding and fusing those researches to our social functions, a model of symbiotic space

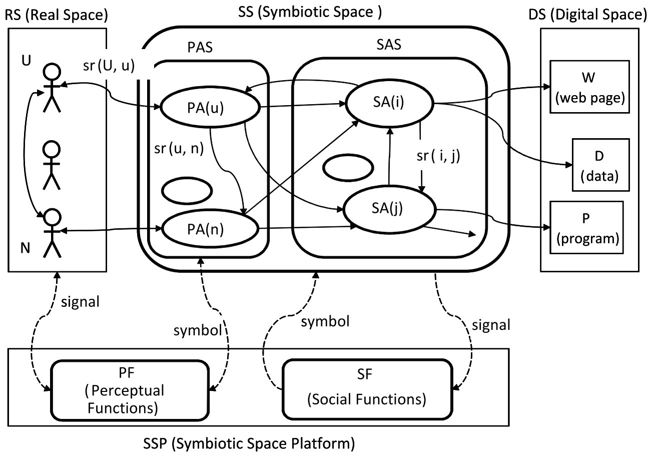

Fig. 3 The framework of symbiotic computing.

and its platform to apply the social functions to Information Explosion are designed in the following subsection.

3.2 Model of Symbiotic Space

The agent-based model of SS in Fig. 3 is composed of PAS (Personal Agents Space), SAS (Social Agents Space) and a set of SR (Symbiotic Relations) as follows.

$$SS = <PAS, SAS, SR>$$

PAS and SAS denote a set of PAs and SAs respectively. SR is a set of symbiotic relations between agents in SS and between agents and users as follows;

$$SR = \{sr(i, j) \mid sr(i, j) = <i, j, view(i, j)> \text{ is an arc from } i \text{ to } j \text{ labeled } view(i, j), i \text{ and } j \text{ are identifiers of agents and users}\}$$

Let $ag(i)$ be an agent whose identifier is i. A $view(i, j)$ is a description to represent information which $ag(i)$ saves in itself to use when $ag(i)$ interacts with $ag(j)$. The $view(i, j)$ is updated after the interaction is finished. An identifier is a unique name that is given when the agent is registered in SSP. A $view(i, j)$ is modeled by a knowledge representation of PDM [39] which is an extended semantic network model. Let $SA(i)$ be an agent belonging to SAS, then

$$SA(i) = <G(i), DEC(i), WM(i), SV(i), CRI(i)>$$

where $G(i)$ is a set of goals of $SA(i)$, $DEC(i)$ is a decision function to make a plan which is to be transformed into a sequence of actions. $WM(i)$ is a knowledge base for $SA(i)$ to understand SS and DS, $SV(i)$ is a Symbiotic Vector which is a description consisting of symbiotic relations and $CRI(i)$ is a set of criteria that are represented by rules to register and update $SV(i)$.

Let U be a name of a user and $PA(u)$ be an personal agent whose identifier is described by u, that serves only a user U, then

$$PA(u) = <INT(u), G(u), DEC(u), WM(u), SV(u), CRI(u)>$$

where $INT(u)$ is a set of functions that $PA(u)$ uses to interacts with a specific user using PF including a dialog box, vocal interface and so on. $G(u)$ is a set of goals including user's satisfaction, user's safeness etc., $DEC(u)$ is a decision function to make a plan

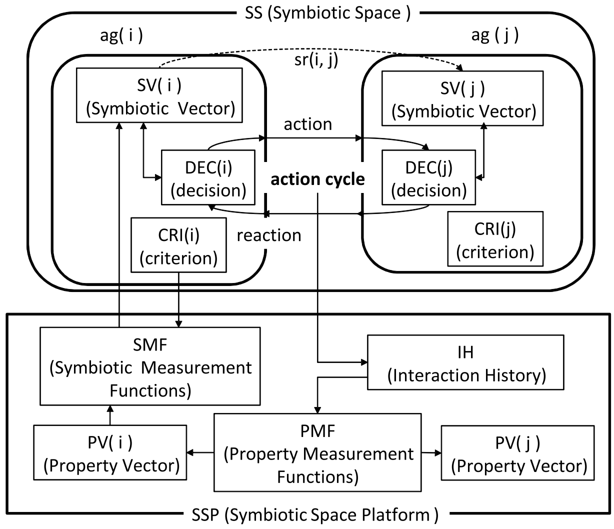

Fig. 4 Property vector and symbiotic vector.

to achieve $G(i)$, $WM(u)$ is a knowledge base for $PA(u)$ to understand the user, user's surrounding, RS and SS. $SV(u)$ is a Symbiotic Vector with agents in SS. $SV(u)$ includes symbiotic relation $sr(U, u)$ between the user U and $PA(u)$. $CRI(u)$ is a set of criteria which represent rules to register and update the $SV(u)$.

A message between agents is based on FIPA Agent Communication Language (FIPA-ACL) [40]. The communication protocol between agents is based on an agent framework named OMAS [39]. In the framework, because agents run in a coterie using UDP protocol, SSP can pick up all the messages and analyze them. Messages between coteries are communicated using TCP over the Internet. Using this protocol, SSP in **Fig. 4** can monitor all interactions between the agents. A message m between two agents is described by;

$$m = <header, body, timeout>$$

where header is a list of items of "from," "to," "protocol-name," "reply-to" etc. The body is the contents of m and the timeout is the duration, the sender agent waits to receive the response message.

4. Symbiotic Relations and its Maintenance Mechanism

In this section, the architecture of an agent SSP is designed to find and maintain symbiotic relations in SS. In this framework, an agent is supposed to be designed, implemented and registered on SSP by a provider of the agent. After the registration, SSP observes interaction of the agent with the other agents. A primitive interaction between the two agents is called Action Cycle defined in the following subsection. We introduce Property Vector in the next section to record the results which SSP continuously observe and analyze time series of interaction between agents. Next, a mechanism to create and maintain symbiotic relations autonomously is designed as shown in Fig. 4.

4.1 Action Cycle

An action cycle, shown in Fig. 4, is defined by a time sequence of actions and reactions which starts at a begin message of an agent and ends at an end message defined in the header part of the messages. A simple example of an action cycle consists of an action to send a request message and a reaction to send an answer message for it. An action cycle may end by a time-out event if the answer message is not received by the agent.

Let $ac(i, j, t)$ be a list of headers of messages in an action cycle between an agent $ag(i)$ and an agent $ag(j)$ that $ag(i)$ started the action cycle at time t. After this section, $ag(i)$ means a general agent that belongs to either PAS or SAS. IH(i) is a set of action cycles that an agent i started in past time, that is,

$$\mathrm{IH}(i) = \{ac(i, j, t) \mid ac(i, j, t) \text{ begins at time } t \text{ by } ag(i) \text{ with } ag(j)\}.$$

IH is a set of IH(i) for all i in Fig. 4. SSP observes all the interaction between agents and between users and agents, and saves them into IH.

4.2 Property Vector

Let $p(i, j)$ be a property of $ag(i)$ to describe relations to $ag(j)$ as follows;

$$p(i, j) = <i, j, (p\text{-}att, v)^*>$$

where *p-att* is a name of an attribute to define a statistical feature of interactions between $ag(i)$ and $ag(j)$. A symbol "*" means iteration of the tuple. A v is a set of numerical numbers and strings of characters that are calculated by a function of Property Measure Function (PMF) autonomously by time series analysis methods from patterns of interaction stored in IH. A *p-att* defines a statistical measure of interactions between agents such as frequency of a specific pattern of sequences of messages.

A Property Vector of $ag(i)$ is denoted $PV(i)$ and is described as follows;

$$PV(i) = \{p(i, j) \mid p(i, j) = <i, j, (p\text{-}att, v)^*>, \\ j \text{ is the name of agent which appears in IH}(i)\}$$

The $PV(i)$ is stored in SSP since $ag(i)$ was registered on SSP to run. SSP monitors all interactions between agents in SS and saves them in IH to update the $SV(i)$ by PMF.

4.3 Symbiotic Vector

A symbiotic relation between agents is defined in SS to promote collaboration between agents to connect user's requirement with resources such as data, programs in DS. A Symbiotic Vector of an agent i, denoted as $SV(i)$, is defined by an array of symbiotic relations as follows;

$$SV(i) = \{sr(i, j) \mid j \text{ is a name of agent that appears in IH}(i), \\ \text{where } sr(i, j) = <i, j, (s\text{-}att, v, r)^*>\}$$

where *s-att* is a name of an attribute to define a feature of relationships between $ag(i)$ and $ag(j)$ from a view point of $ag(i)$'s benefit. A v of each *s-att* is a set of numerical number and strings of character that are selected by $CRI(i)$. A r is a benefit description that $CRI(i)$ evaluated the relation $sr(i, j)$ based on the $ag(i)$'s criteria.

The $SV(i)$ is stored in an agent $ag(i)$ by Symbiotic Measure Functions (SMF) in SSP since the agent $ag(i)$ was registered on

SSP to run. The SMF updates values of $SV(i)$ autonomously when any value in $SV(i)$ is changed. Contents of $CRI(i)$ defined in $ag(i)$ is a set of rules for SMF to initialize and update $SV(i)$, that are defined by a developer of the agent $ag(i)$ in order for the agent to find better relationships with other agents through history of interactions. $DEC(i)$ refers to $SV(i)$ to find agents to ask for tasks and information which $ag(i)$ was requested by other agents or a user. $DEC(i)$ also updates the $SV(i)$ referring to $CRI(i)$.

A value of $sr(i, j)$ defines a meaning of a feature of a relationship that is analyzed by SMF using statistical quantities described in $PV(i)$. The meaning is defined by heuristics of a developer of the $ag(i)$ described in form of tuples of (attribute value) in $SV(i)$.

5. Symbiotic Computing and Information Explosion

In earlier sections, Symbiotic Space(SS) and the symbiotic relations in SS to connect users in RS and resources in DS have been proposed. In the proposed model, SSP maintains the symbiotic relation autonomously to find better relation for gaining user's benefit. In this section, we discuss the feasibility of Symbiotic Computing to reduce users' burden due to Information Explosion.

5.1 Example Problem

This subsection discusses the restaurant information retrieval problem, which is a typical problem for Information Explosion. Generally a user gathers a lot of information from many web pages. Too much amount of information or too many retrieval conditions often makes the judgment of appropriate information very difficult. It is also true in case of the restaurant information retrieval problem between User-A and User-B in **Fig. 5**.

Let us suppose that User-A (Host) plans to find a restaurant to take dinner after meeting with User-B (Guest), who is a new acquaintance. Before the meeting, User-A finds a sushi-restaurant near the meeting place using WWW and sends a mail to invite him there. If User-B does not like raw fish, he asks User-A to find another restaurant rather than the sushi-restaurant. After retrieving WWW, User-A proposes a good sukiyaki-restaurant near the station. Unfortunately, User-B visited another sukiyaki-restaurant the previous day, then User-A tries to find again another restaurant suitable for both of them.

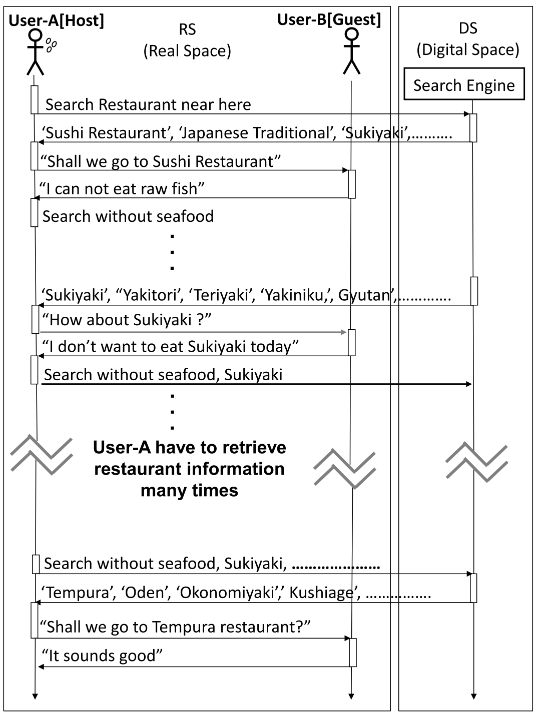

Fig. 5 Sequences of message exchange between User-A and User-B.

Figure 5 shows the time sequences of messages among User-A, User-B and DS. In this case, as both User-A and User-B do not have necessary information, User-A (Host) has to access web pages many times to find suitable restaurant information near the meeting place.

Actually, in order to retrieve appropriate restaurant information, one needs to consider many conditions and limitations. For example, generally, one has to consider the day's weather condition, temperature, proximity of the restaurant etc. As for the personal preferences one has to consider guest's likes and dislikes, difference of customs, health condition etc. Especially, it is also difficult to obtain too much personal information of other person because of privacy.

5.2 Reduction of Message Passing by Using Symbiotic Computing

Figure 6 represents the resulting time sequences of messages after the use of Symbiotic-Computing approach for reducing burdens due to Information Explosion. First, User-A requests PA(A) (personal agent of User-A) to find a restaurant to invite User-B to dinner after the meeting. Because PA(A) does not know the preferences of User-B, it communicates with PA(B) (personal agent of User-B) to ask for User-B's preference of food. Let us suppose that PA(B) knows the invitation by User-A after the meeting, it sends the information of User-B back to PA(A). In this case, PA(B) might confirm if it can provide the information to User-A. PA(A) chooses keywords to retrieve a good restaurant, that may include types of food, place, time, number of person, smoking/nonsmoking, price etc.

In Fig. 6, PA(A) chooses an SA(k) (social agent k) that has rich

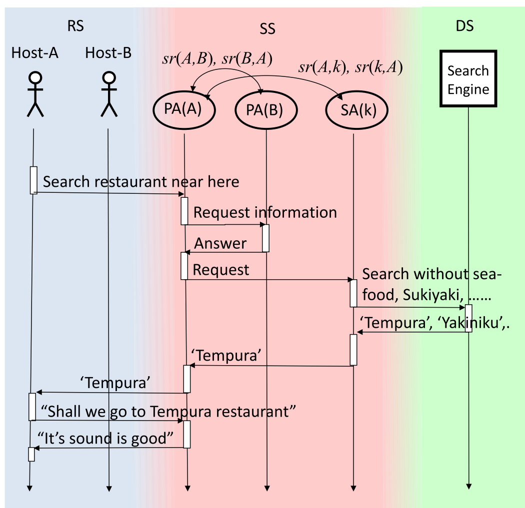

Fig. 6 Symbiotic computing approach for reducing the burden of information explosion.

information for the keywords using a symbiotic relation *sr*(A, k) in $SV(A)$ that is maintained by the SSP and PA(A) as represented in Fig. 4. PA(A) knows that SA(k) is quite suitable for the request empirically. After the reply from SA(k), PA(A) inquires about candidates of restaurants for invitation. Then, User-A may choose a restaurant to make the reservation without exchanging messages with User-B and DS. The number of message sending shown in Fig. 5 is fairly reduced as is shown in Fig. 6 as a result of using symbiotic relation in SS.

5.3 Effect of Symbiotic Relation

In this subsection, the effect of Symbiotic Relation mentioned in Section 4 and shown in Fig. 4 is explained. The mechanism of SS stated in Section 3 works on the assumption that a personal agent can understand requests, preference, aim, social activity, etc. of a specific user using the PF. Each SA is supposed to be designed by a developer and registered in SS. Initially, the SA has no symbiotic relation with other agents in SS. The SA begins to work based on its goal, such as crawling WWW, given by the developer. If the SA receives a request from PA and the SA can answer the request, then SA sends a response message to PA. The action cycle is saved in the IH in SSP and the mechanism updates the SV of the SA. SSP observes every message concerning the SA and saves header parts of messages into IH.

PMF is a set of functions to find new action cycle in IH. PMF deals with it statistically and save it to *PV* of PA. For example, if an action cycle of PA with SA consists of sequence of messages with the header including message types (performatives) of "request," "answer," "thank you" and "you are welcome," then the number of the attribute of "success" of *p*(PA, SA) in *PV* of the PA is increased. Many attributes corresponding to patterns of action cycles are predefined in *PV*.

A *sr*(PA, SA) includes a list of *s-att* corresponding to each interest of PA based on its goal. SMF in Fig. 4 is controlled by *CRI* including current interest of PA. If SMF watching the *PV* finds a "success" action cycle with SA, SMF ranks up a value of the *s-att* in *sr*(PA, SA) corresponding to the current interest from "normal" to "good."

Let M be the number of users and N be the number of resources in DS. All relationships among users and resources in SS construct a complete graph whose size is $(M + N) * (M + N)$. If the search engine tries to provide services to satisfy all users, it will leads to Information Explosion. In order to reduce the burden of Information Explosion, the concept of symbiotic relation based on Symbiotic Computing has been proposed and a mechanism to maintain them autonomously using *PV* and SV has been designed.

6. Conclusion

The authors emphasized the importance of concept of 'Symbiosis' as a novel computing paradigm towards post-modern information systems at IPSJ Workshop held in 1994 [2]. Furthermore, the concept of Symbiotic Computing has been proposed to bridge the gap between users and the Digital Space that is getting wider and wider. To achieve the symbiosis, the concept of Flexible Computing is introduced in order to build a fundamental infrastructure for the Symbiotic Computing. The project on the Flexible Computing that ran since 1999 until 2004, designed models and architecture of the Flexible Network. The project also developed various kinds of Symbiotic Computing-based applications such as symbiotic offices, along with expanding Flexible Computing, and finally, the total concept was renamed as Symbiotic Computing.

In this paper, an overview of Symbiotic Computing is addressed, and next it is applied to design agent-based model aiming to solve the problem of Information Explosion by bridging the gap between RS and DS. The feasibility of using Symbiotic Computing is shown by a typical application example which otherwise can cause Information Explosion.

The Symbiotic Computing consists of Social Computing and Perceptual Computing as stated in Section 2.2. In this paper, we focused our work on Social Computing to meet our goal to combat the problem of Information Explosion. The mechanism of Symbiotic Space proposed in Section 3 works on the assumption that a personal agent can understand requests, preference, aim, social activity, etc. of a specific user. Perceptual Computing is not explained here in detail because of the lack of space. We are promoting the researches on applications such as care support systems and telework incorporating the Perceptual Computing running on the SSP.

Reference

[1] Kitsuregawa, M.: Info-plosion: Retrospection and Outlook, *The Journal of the Institute of Electronics, Information, and Communication Engineers*, Vol.94, No.8, pp.662–666 (2011).

[2] Shiratori, N.: Post-Modern Distributed Systems, *Proc. Multimedia Communication and High-speed Intelligent Distributed Cooperated Computing Symposium 2010* (*IPSJ*), pp.1–7, Keynote Speech (1994). This paper was upgraded and appeared in *IPSJ Magazine* with the same title, Vol.36, No.9, pp.811–814 (1995).

[3] Shiratori, N., Sugawara, K., Kinoshita, T. and Chakraborty, G.: Flexible Networks: Basic Concepts and Architecture, *IEICE Trans. Commun.*, Vol.E77-B, No.11, pp.1287–1294 (1994).

[4] Shiratori, N., Suganuma, T., Sugiura, S., Chakraborty, G., Sugawara, K., Kinoshita, T. and Lee, E.S.: Framework of a Flexible Computer Communication Network, *Computer Communications*, Vol.19, pp.1268–1275 (1996).

[5] Fujita, S., Sugawara, K., Kinoshita, T. and Shiratori, N.: An Approach to Developing Human-Agent Symbiotic Space, *Proc. 2nd Joint Conference on Knowledge-Based Software*, pp.11–18, Bulgaria (1996).

[6] Fujita, S., Sugawara, K., Kinoshita, T. and Shiratori, N.: ADIPS Framework and It's Application to Symbiotic Space on Network Environment, *ICPP98*, Minneapolis (Sep. 1998).

[7] Suganuma, T., Imai, S., Kinoshita, T., Sugawara, K. and Shiratori, N.: A Flexible Videoconference System based on Multiagent Framework, *IEEE Trans. Syst. Man, and Cybernetics Part A*, Vol.33, No.5, pp.633–641 (2003).

[8] Fujita, S., Hara, H., Sugawara, K., Kinoshita, T. and Shiratori, N.: Agent-based Design Model of Adaptive Distributed Systems, *International Journal of Artificial Intelligence, Neural Networks, and Complex Problem-Solving Technologies*, Vol.9, No.1, pp.55–68 (July/Aug. 1998).

[9] Suganuma, T., Sugawara, K. and Shiratori, N.: Symbiotic Computing: Concept, Architecture and its Applications, *Proc. 4th International Conference on Ubiquitous Intelligence and Computing*, pp.1034–1045, Invited Paper (2007).

[10] Shiratori, N.: Towards Symbiotic Information Society, *2008 International Computer Symposium*, Keynote Speech (2008).

[11] Shiratori, N., Chakraborty, D., Takahashi, H., Suganuma T. and Takeda, A.: Beyond Ubiquitous Information Society — A Step Towards Human-Computer Symbiosis, *Proc. NTC International Conference 2009*, Keynote Speech (2009).

[12] Shiratori, N., Hashimoto, K., Chakraborty, D., Takahashi, H., Suganuma, T., Nakamura, N. and Takeda, T.: Kurihara Green ICT

Project — Towards Symbiosis between Human's Life and Nature, *Journal of Internet Technology*, Vol.12, No.1, pp.1–11 (2011).
[13] Symbiotic Computing (online), available from ⟨http://symbiotic.agent-town.com/⟩ (accessed 2011-10-13).
[14] Weiser, M.: The Computer for the 21st Century, *Scientific American Special Issue on Communications, Computers, and Networks* (Sep. 1991).
[15] Lyytinen, K. and Yoo, Y.: Issue and Challenges in Ubiquitous Computing, *CACM*, Vol.45, No.12, pp.63–65 (2002).
[16] IST Advisory Group: Scenarios for Ambient Intelligence in 2010, European Commission (2001).
[17] Matsuyama, R., Sugimoto, A., Sato, Y. and Kawashima, H.: Developing Man-Machine Symbiotic Systems, *Journal of the Japanese Society for Artificial Intelligence*, Vol.19, No.2, pp.257–266 (2004) (in Japanese).
[18] Ramos, C., Augusto, J.C. and Shapiro, D.: Ambient Intelligence — the Next Step for Artificial Intelligence, *IEEE Intelligent Systems*, Vol.23, No.2, pp.15–18 (2008).
[19] Murata, M.: Towards Ambient Information Society, *Journal of the Institute of Electronics, Information and Communication Engineers*, Vol.93, No.3, pp.233–238 (2010) (in Japanese).
[20] Suganuma, T., Lee, S., Kinoshita, T. and Shiratori, N.: An Agent Architecture for Strategy-centric Adaptive QoS Control in Flexible Videoconference System, *New Generation Computing*, Vol.19, No.20, pp.173–191 (2001).
[21] Suganuma, T., Imai, S., Kinoshita, T., Sugawara, K. and Shiratori, N.: A Flexible Videoconference System based on Multiagent Framework, *IEEE Trans. Syst. Man, and Cybernetics part A*, Vol.33, No.5, pp.633–641 (2003).
[22] Kinoshita, T. and Sugawara, K.: ADIPS Framework for Flexible Distributed Systems, *Multiagent Platforms*, Ishida, T. (Ed.), Lecture Notes in Artificial Intelligence 1599, pp.18–32, Springer-Verlag (1999).
[23] Uchiya, T., Maemura, T., Hara, H., Sugawara, K. and Kinoshita, T.: Interactive Design Method of Agent System for Symbiotic Computing, *International Journal of Cognitive Informatics and Natural Intelligence*, Vol.3, No.1, pp.57–74 (2009).
[24] Konno, S., Zhang, X., Sugiyama, T., Takahashi, S., Hara, H. and Fujita, S.: On a View Model of Agents in the Cyber Office, *Proc. 12th International Conference on Information Networking*, pp.123–126, Japan (1998).
[25] Sugawara, K.: Agent-based Application for Supporting Job Matchmaking for Teleworkers, *Proc. IEEE International Conference on Cognitive Informatics*, pp.137–142 (2003).
[26] Sugawara, K.: Cyber Office in Human-Agent Symbiotic Space for Home-based Teleworkers, *Proc. 10th International Telework Conference and Workshops*, Preston (Sep. 2005).
[27] Fujita, S., Sugawara, K. and Barthes, J.P.: Location-Aware Services using GPS and Knowledge Management, *Proc. 11th International Symposium on the Management of Industrial and Corporate Knowledge*, Stellenbosch (Aug. 2006).
[28] Takahashi, H., Yamanaka, K., Izumi, S., Tokairin, Y., Suganuma, T. and Shiratori, N.: Gentle supervisory system based on integration of environmental information and social knowledge, *International Journal of Pervasive Computing and Communications*, Vol.6, No.2, pp.229–247 (2010).
[29] Izumi, S., Yamanaka, K., Tokairin, Y., Takahashi, H., Suganuma, T. and Shiratori, N.: Ubiquitous supervisory system based on social contexts using ontology, *Mobile Information Systems* (*MIS*), Vol.5, No.2, pp.141–163 (2009).
[30] Suganuma, T., Sugawara, K., Kinoshita, T., Hattori, F. and Shiratori, N.: Concept of Symbiotic Computing and its Agent-Based Application to a Ubiquitous Care-Support Service, *International Journal of Cognitive Informatics and Natural Intelligence*, Vol.3, No.1, pp.34–56 (2009).
[31] Sugawara, K.: Agent-based Support System for Project Teaming for Teleworkers, *Intelligent Agents and Multi-Agent Systems*, LNAI3371, pp.279–290, Springer (2005).
[32] Bobrow, D.: Dimensions of interaction, *AI Magazine*, Vol.12, No.3, pp.64–80 (1991).
[33] Castelfranchi, C.: The theory of social functions: Challenges for computational social science and multi-agent learning, *Journal of Cognitive Systems Research*, Vol.2, No.1, pp.5–38 (2001).
[34] Stirlin, W.C.: Social Utility Functions — Part I: Theory, *IEEE Trans. Syst. Man, and Cybernetics Part C*, Vol.35, No.4, pp.522–532 (Nov. 2005).
[35] Stirlin, W.C.: Social Utility Functions — Part II: Applications, *IEEE Trans. Syst. Man, and Cybernetics Part C*, Vol.35, No.4, pp.533–542 (Nov. 2005).
[36] Golder, S. and Huberman, B.A.: Usage Patterns of Collaborative Tagging Systems, *Journal of Information Science*, Vol.32, No.2, pp.198–208 (2006).
[37] Heymann, P., Koutrika, G. and Garcia-Molina, H.: Can Social Bookmarking Improve Web Search?, *1st ACM International Conference on Web Search and Data Mining* (*WSDM'08*), Stanford, CA, pp.11–12 (Feb. 2008).
[38] Wang, F.-Y., Zeng, D., Carley, K.M. and Mao, W.: Social Computing: From Social Informatics to Social Intelligence, *IEEE Intelligent Systems*, Vol.22, No.2, pp.79–83 (Mar. 2007).
[39] Barthes, J.-P.A.: OMAS: A flexible multi-agent environment for CSCWD, *Future Generation Computer Systems*, Vol.27, pp.78–87 (2011).
[40] FIPA: Specification part 2, Agent Communication Language (1999).

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