big data and cognitive computing

MDPI

Article

Memory Recall Support System Based on Active Acquisition and Accumulation of Memory Fragments

Kaho Takahashi [1,2,*], Takumi Kato [1,2] and Tetsuo Kinoshita [1,2]

1 Research Institute of Electrical Communication, Tohoku University, Katahira 2-1-1, Aoba-ku, Sendai 980-8577, Japan; takumi@k.riec.tohoku.ac.jp (T.K.); kino@riec.tohoku.ac.jp (T.K.)
2 Graduate School of Information Sciences, Tohoku University, Aoba 6-3-09, Aramaki-aza, Aoba-ku, Sendai 980-8579, Japan
* Correspondence: kaho-t@k.riec.tohoku.ac.jp; Tel.: +81-22-217-5412

Received: 23 March 2018; Accepted: 13 May 2018; Published: 17 May 2018

Abstract: With the widespread use of wearable sensors, cloud services, social networking services (SNS), etc., there are various applications and systems that record information on users' daily activities and support recalling these activities. In various situations in everyday life, it is useful to recall and refer to past events by utilizing such information; therefore, there are increasing expectations surrounding a memory recall system that supports users' activities. In this research, we aim to realize a system that acquires records of users' experiences, transforms these records as Active Information Resources, autonomously manages the accumulated records based on the record's metadata, and supports users' human memory recall. In this paper, we describe the design and implementation of a basic framework for accumulating records on daily activities and providing information related to past experiences according to the user's request. We also present evaluation experiments using the implemented system.

Keywords: memory recall support; lifelog; autonomous cooperation; active information resource

1. Introduction

Recent years have seen an increase in the possibility to record our lives in cyberspace. Due to the widespread use of smartphones, it is easy to record daily activities and experiences electronically, for example, in the form of photos, memos, and position information. It is also becoming common to document experiences and emotions by using social networking services (SNSs), and to save communication content such as message exchanges, telephone calls, and emails. Furthermore, with the development of various sensor devices and service robots, generally called Internet of Things (IoT) devices, it is possible to acquire environmental information and vital data from sensors and to save various experiences of everyday life as electronic data. Electronic records of such lives are generally utilized to analyze and review experiences.

It is known that humans recall their memories by associating cues with stored past experiences in their brains [1], e.g., when visiting the same place, listening to related words, etc. However, it is known that there are memories that cannot be remembered when necessary, because of the passage of time since the experience, and the decline of the importance of the memory. For example, in everyday life, people sometimes forget to purchase items which they wanted at supermarkets. In addition, they often cannot remember the name of a person they have met before. Also, patients with memory impairment or elderly people cannot recall things in various situations, which may lead to forgetting important tasks such as taking medicine, causing problems in important communications.

Records can be used to support the recall of memories, which cannot be recalled by oneself. For example, by posting a message with a photo on the SNS, it becomes possible to electronically accumulate memories of events such as travels and parties, and to review the content and related emotions later. It is also possible to memorize where the user was at a particular time on a particular day by accumulating a record of location information.

However, there is a burden on using the current recall support based on a lifelog, thus this is neither appropriate nor sufficient. First, in order to use lifelogs effectively, humans need to remember the cues such as the stored location of records and the accurate date and time of target memory. For example, if a user took a picture in a restaurant in the past, recorded what he/she ate, the name of the shop, or the atmosphere inside the shop, then the user could review the information later. However, in order to see the picture, it is necessary to memorize the title and date of the photograph to retrieve it, and it is difficult for a user to manage all the information necessary for retrieving the lifelog. Also, in human memory, much of the information classified as visual, auditory, and emotional are related, therefore it is possible that a clearer memory can be recalled by using various records. However, combinations of different types of records entail the burden of using multiple different services which is more difficult than searching and recalling a single record.

In order to realize an effective memory recall support system, it is necessary, not only to record and accumulate the user's life, but also to search, combine, and utilize the recorded information. In this research, we aim to realize a memory recall support system that provides the content of memory records that the user cannot normally remember in a visual or auditory way. In our approach, lifelogs, electronic files, etc., are called fragmentary records related to the user's experiences, which are transformed into a processing body called an Active Information Resource (AIR). Our aim is that the AIRs of memory autonomously build the relations among themselves based on the users' situation and the environment. The AIRs maintain, manage themselves, and autonomously cooperate in response to the user requests to realize memory recall support.

In this paper, we aim to provide effective recall support of users' past experiences. In particular, we focus on the recall of experiences involving a wide variety of memory fragments, to enable accurate and detailed recall support with little effort. This paper aims to propose a method to automate tasks required for screening and accumulating information and to reduce the burden of work done by users when supporting user activities using information obtained via means of collection such as lifelogs. Also, the reason why we focused on the task of memory recall support is because it is useful as a means to verify the ability to systematically extract acquired and accumulated information as necessary. Target memories are events such as traveling, meetings, lunch, and meeting people. In this paper, we define information resources such as lifelogs and files collected for recall support as memory fragments. In general, in the human brain, past experiences are stored as episodic memory containing temporal and spatial information associated with other memories [2–4]. Therefore, in this paper, we define memory recall as finding memory fragments that show the content of experiences such as time, place, emotions, and related people and objects, as well as other similar experiences.

In Section 2, we present prior research on the technologies that record users' experiences, and then describe target problems of this research. Section 3 explains the memory recall support system based on the active acquisition and the accumulation of memory fragments proposed in this research. Section 4 describes the implementation of the system proposed in Section 3. Section 5 describes the results of evaluation experiments with multiple users, using the system implemented in Section 4. Section 6 is the conclusion.

2. Related Work on the Acquisition and Utilization of Records on User Experiences and Target Problems

2.1. Related Work on the Acquisition and Utilization of Records on User Experiences

Many investigations on lifelog acquisition for memory recall support have been carried out. There is research on recall support by utilizing the surrounding situation, and the mental and physical condition acquired from wearable sensor devices [5,6]. However, since these experience records are accumulated in various forms, it is difficult to utilize them in an appropriate way based on the situations of users' needs.

There have also been various investigations on recall support using lifelogs and files [7,8]. Forget-me-not [9] supports the personal memory recall of users by dedicated compact wireless communication equipment, using the information of people in the same room, such as email exchange history, telephone, related files, and so on. This research makes it easier to search records which the user wants to search by the time, place, and people involved in the recall target experience. In systems that support recall of social contacts [10,11], it is possible to use information of interactions as memory cues by collecting information on the surroundings when the user interacts with the information of people obtained by the sensors, as well as the information such as personal information from the Web page. However, it is possible that necessary information is not appropriately provided because the cue for retrieval needs to match the experience information exactly. In addition, research has been conducted to support retrieval and recollection by showing records on a timeline [12], adding 5W1H information to the photographs [13], or introducing the location and time in the search queries [14].

As described, there have been several investigations on the acquisition and utilization of records of users' experiences, but there are restrictions on the method of utilization (extraction and retrieval) and the format of records. Therefore, in various events involving diverse types of records, there is a lack of technologies for recalling experiences by effectively utilizing a full set of memory fragments.

2.2. Target Problem

In this research, we aim to realize memory recall support utilizing memory fragments. In human memory, experiences are composed of the information of multiple memory fragments, and the experiences are generally related to each other. The relevance between the experiences depends on their content, which is updated and changes upon the emergence of new memories of experiences. For recall support, it is necessary to link multiple types of memory fragments and to establish relationships of experiences that can be automatically updated by changing circumstances. With the AIR concept for memory fragments, we aim to address the following three problems.

P1 There is no function for utilizing a wide variety of memory fragments with different file formats in heterogeneous services and applications

A human experience can be represented by combining multiple types of memory fragments. To use multiple kinds of memory fragments, it is necessary for users to manually add and process information on memory fragments. In that case, it is difficult to simply combine and compare different kinds of memory fragments with each other, due to the difference of the type of metadata to compare.

P2 There is no function for constituting an experience by arranging and combining memory fragments, namely, addition, update, and deletion

The combination requirement of memory fragments varies, depending on the situation of the user and the environment. Therefore, it is difficult to uniformly manage the experience of users composed of diverse memory fragments. When a memory fragment is added, updated or deleted, it creates a burden for the user to consider and maintain the memory fragments.

P3 There is no function for retrieving the effective set of memory fragments for users' ambiguous recall requests

Human memory can be recalled based on a chain of memories related to past experiences, so the appropriate set of memory fragments changes dynamically. Therefore, in order to respond to users' requests, it is necessary to appropriately select memory fragments by considering the connection of experiences in human memory.

In this research, we try to realize active recall support by applying the Active Information Resource (AIR) concept [15] to memory fragments such as lifelogs and files. An AIR is a software process structured to support and promote the use of information and knowledge, by introducing a function that enables information resources such as document files and image files to autonomously process and/or respond to user requests.

An AIR is an information resource to which the utilization support knowledge and the utilization support function shown in Table 1 are added. An AIR makes it possible to strengthen and expand the structure of information resources and supports the use and reuse of resources. In this way, as shown in Figure 1, each AIR has a function of manipulating information resources and cooperating with the other AIRs based on the content and knowledge of information resources, and the architecture allows the various requests to be actively dealt with.

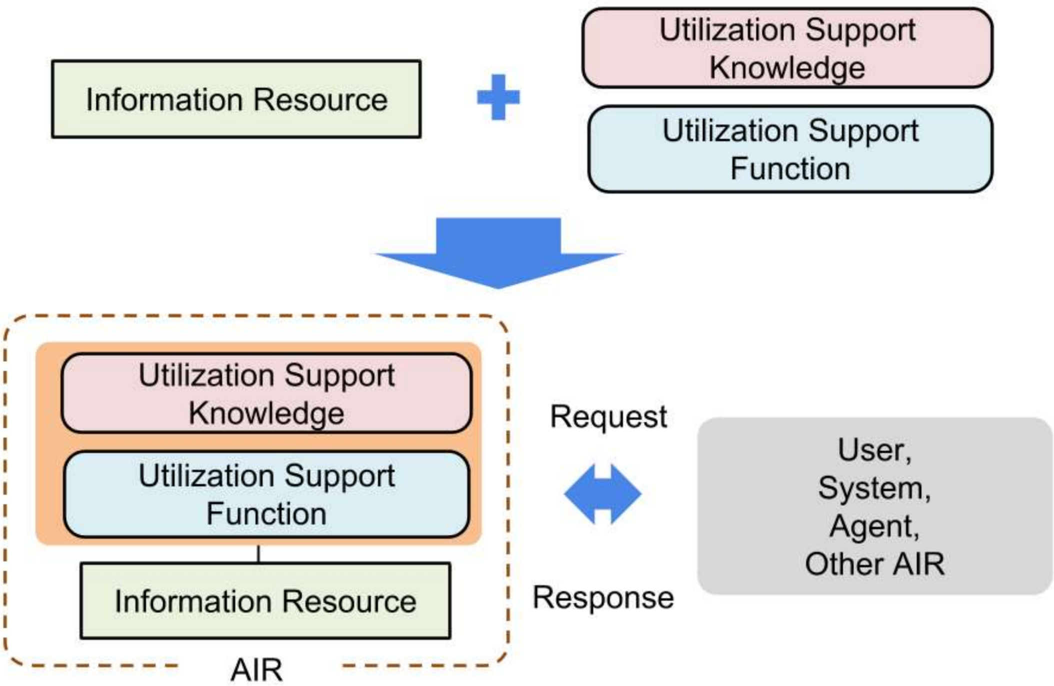

Figure 1. Architecture of an Active Information Resource (AIR).

Table 1. Components of an Active Information Resource (AIR).

Component	Content
Utilization Support Knowledge	Knowledge on the content of the information resource and the utilization method and purpose.
Utilization Support Function	Functions of processing the information resource, cooperation with other AIRs (messaging, information exchange, and interpretation).

In this research, using the AIR concept, we propose a memory recall support system based on actively acquiring and accumulating memory fragments consisting of the following three basic functions to solve the target problems.

S1 Memory fragment activation function based on the AIR concept

A function of transforming a wide variety of memory fragments related to user experience as AIRs, and to make them autonomously operating software processes.

S2 Memory structure construction function by link generation

A function to build relationships among memory fragments of AIRs that present human experiences and their relationships.

S3 Memory fragment recall function by cooperation of AIRs

A function to extract a particular set of linked, networked memory fragments according to the situation and requirements of users realized by autonomous collaboration of AIRs.

In the following sections, we describe in detail the recall support system by realizing these functions.

3. Memory Recall Support System Based on Active Acquisition and Accumulation of Memory Fragments

3.1. Overview of the Memory Recall Support System Based on Active Acquisition and Accumulation of Memory Fragments

In order to solve the problems described in Section 2.2, we propose a system that supports recall by memory fragments, which are autonomously collaborating and linking based on AIRs. Figure 2 shows an overview of the proposed system.

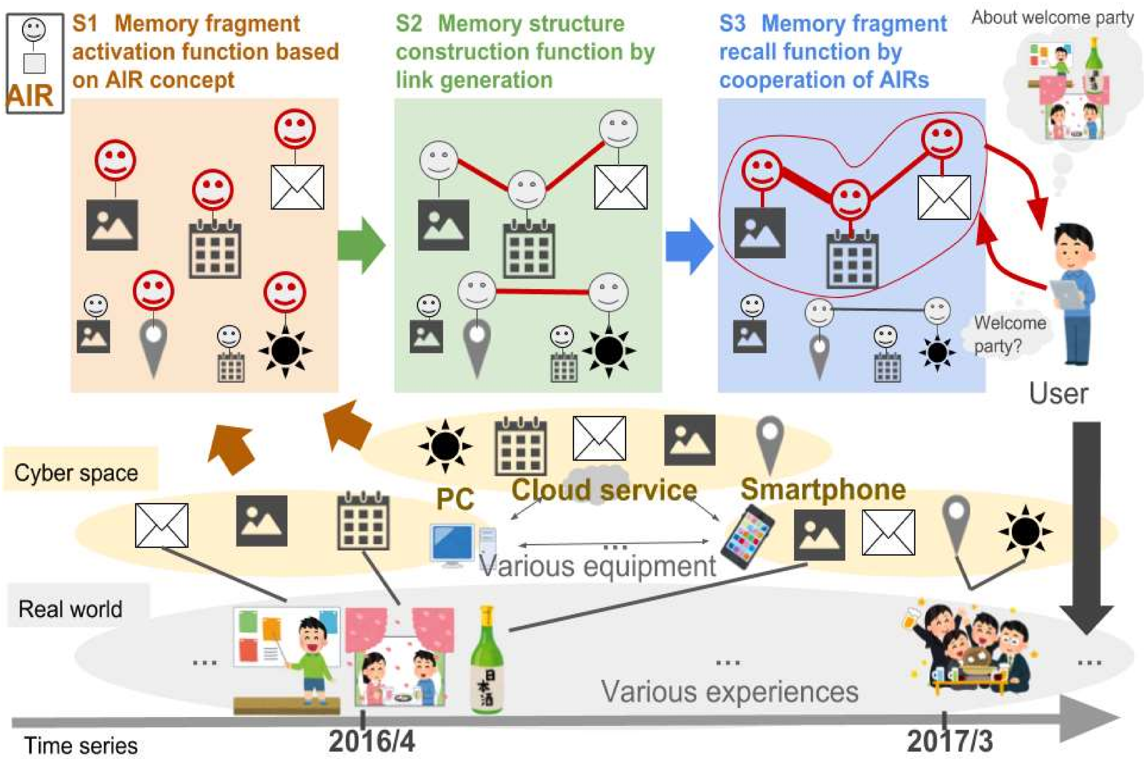

Figure 2. Overview of the proposed memory recall support system based on active acquisition and accumulation of memory fragments.

The proposed recall support system acquires a memory fragment which is the information obtained as a part of the user's experience. The experience of the user represented in this system is an event including not only time and place, but such information as emotions, used documents, related people's information, and so on. The memory fragment is a diverse record of mail, image, voice, etc., generated by the user using various applications and services. It also includes records such as the current position and weather in the daily life of users that can be acquired from sensors, Web services, etc. Furthermore, the lifelog that records the user's action, state, ideas, etc., is used as a memory fragment. For example, memory fragments such as "playing baseball", "meeting a friend", and "preparing for a meeting" are acquired as the outline information of the behavior of the user from the past schedule of the user registered in the digital calendar. It is also possible to acquire the fragments from IoT (Internet of Things) devices such as vital information from sensors or communication robots.

In this system, the memory fragment recorded directly or indirectly by the user is automatically generated as an AIR. The generated AIR autonomously calculates the link strength with the already generated AIRs, and creates links with each other to form a network of AIR groups based on its connections; it is thus the combination of the atomic unit plus its "neighborhood" that triggers recall. When the system performs a user's memory recall, it gives a recall request to the generated AIRs based on the user's request and situation. In response to the request, each AIR sequentially activates highly relevant AIRs that match the request, thereby forming a memory fragment network, which becomes the cues to the memory recall of the user. In addition, the system provides the visualization of the network of memory fragments to support the memory recall.

3.2. Design of the Memory Recall Support System Based on Active Acquisition and Accumulation of Memory Fragments

Figure 3 shows the processing flow of the prototype system, from the acquisition of a memory fragment to the presentation of information in this system. The core part of this system consists of three functions: (S1) Memory fragment activation function based on the AIR concept, (S2) memory structure construction function by link generation, and (S3) memory fragment recall function by cooperation of AIRs. Each function is described in detail below.

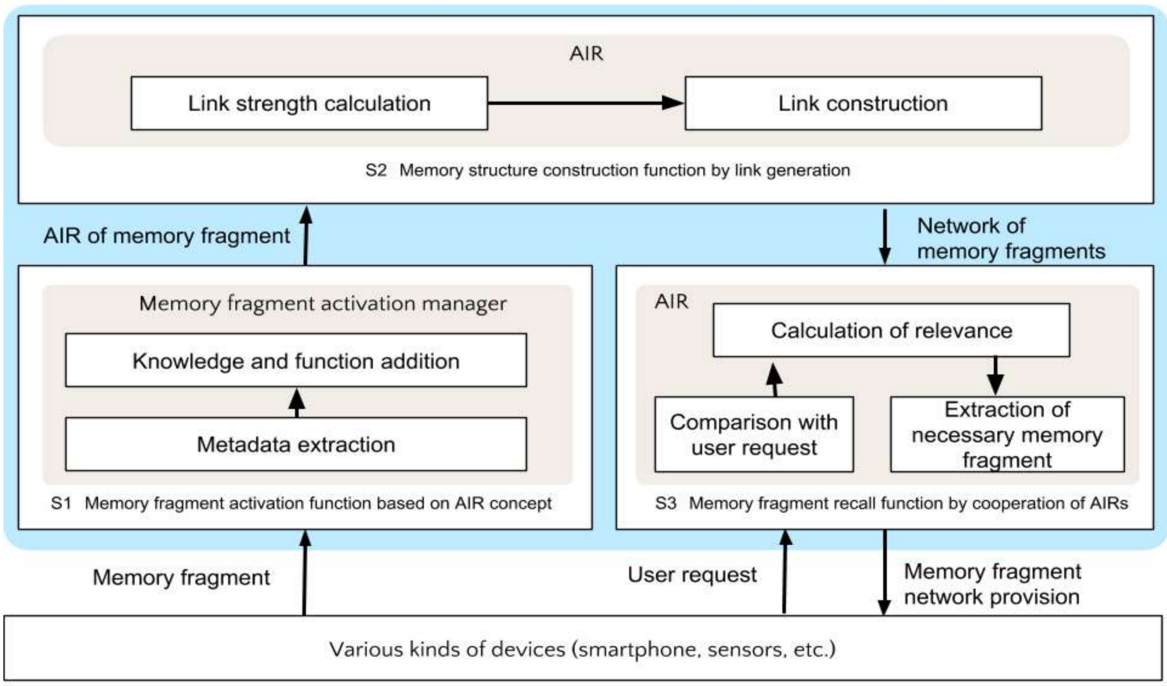

Figure 3. Processing flow of the memory recall support system based on the active acquisition and accumulation of memory fragments.

3.2.1. Memory Fragment Activation Function Based on the AIR Concept

In this function, metadata is automatically extracted from the memory fragment related to the user's experience and processed. By adding knowledge and functions for using the memory fragment, the system transforms the memory fragment into the AIR format, and generates an AIR of the memory fragment that can cooperate autonomously. "Activation" in this function refers to the acquisition of a memory fragment in AIR format so that it can respond actively to later requests.

In the process of acquiring a memory fragment as an AIR, metadata about the target memory fragment is used. Metadata used in an AIR consists of time and location information when the memory fragment was created, and the attributes related to people and objects. This information is defined in comparable format.

The process of extracting metadata from a memory fragment is shown in Figure 4. This function is performed by the memory fragment activation manager, which obtains information from all the memory fragments specified by the user. This manager monitors the memory fragments acquired from the application by using the API to access memory fragments. If a memory fragment that is not an AIR is found, then the metadata used in the AIR extracts the memory fragment and adds it to AIR's utilization support knowledge, thus generating an AIR of this memory fragment. When it is confirmed that all the existing memory fragments have been converted into an AIR, the presence or absence of the updated AIR is checked, and the metadata of the updated AIR is also updated. Furthermore, if there is an AIR of the deleted memory fragment, the manager deletes the AIR and it returns to monitoring memory fragments again.

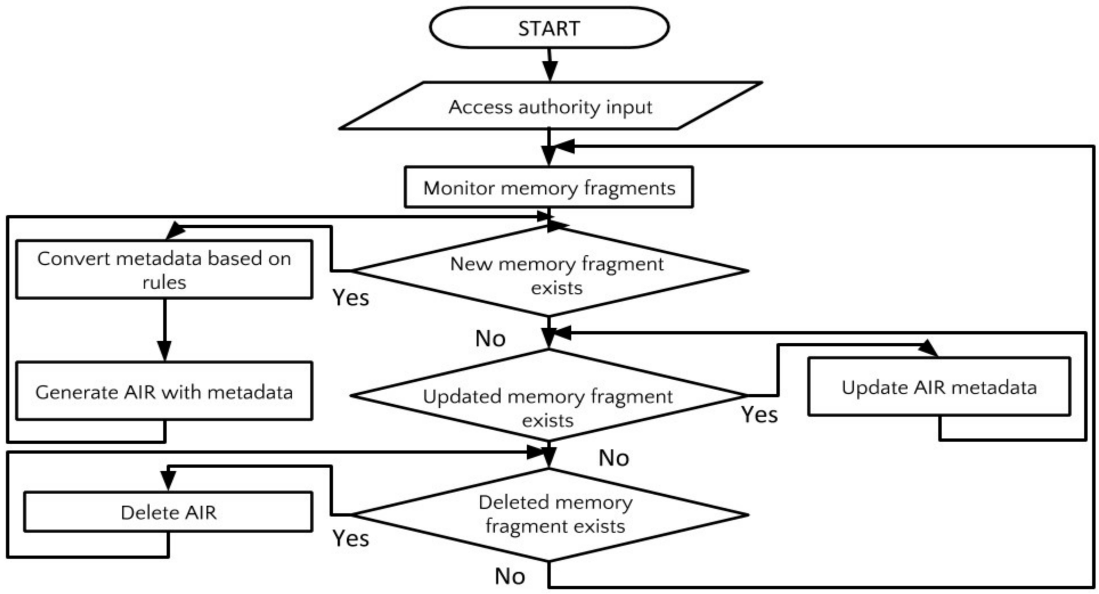

Figure 4. Flowchart of memory fragment activation manager.

Table 2 shows an example of metadata. This is metadata about a schedule that the user added to the calendar. Metadata of this schedule shows that the user made a seminar presentation from 15:00 to 17:00 on 5 April 2016, by SUMMARY (item number 1) and DT (item numbers 2, 3). The last update date and time and the UID indicating the identifier for each schedule are automatically added by the calendar application. These metadata are converted into a format that can be referred to and used by an AIR. For example, in the description example shown in Table 3, keywords are generated by extracting the parts of speech from SUMMARY, DESCRIPTION, and LOCATION in Table 2. It is possible to easily compare content with other memory fragments.

Table 2. Example of metadata that can be acquired (seminar presentation).

No.	Name	Content
1	SUMMARY	Seminar presentation
2	DTSTART	20160405T060000Z
3	DTEND	20160405T080000Z
4	LAST-MODIFIED	20160404T060000Z
5	LOCATION	Research Institute of Electrical Communication, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, JAPAN
6	DESCRIPTION	Self-introduction
7	CALNAME	Calendar A
8	UID	XXXXX@google.com

Table 3. Metadata example used in an AIR (seminar presentation).

No.	Name	Sub No.	Sub Name	Content
1	What	1-1	Title	Seminar presentation
2	When	2-1	Start Time (JST)	20160405150000
		2-2	End Time (JST)	20160405170000
		2-3	Start Time (UNIX)	1459836000
		2-4	End Time (UNIX)	1459843200
3	Where	3-1	Address	2-1-1 Katahira, Aoba-ku, Sendai 980-8577, JAPAN
		3-2	Coordinates	140.87351675, 38.25326033
4	Content	4-1	Keywords	Seminar, Presentation, Self-introduction, Research, Institute, Electrical, Communication
5	About log	5-1	Type	Schedule
		5-2	Save location	Google Calendar, Calendar A
		5-3	ID	XXXXX@google.com

3.2.2. Memory Structure Construction Function by Link Generation

In this function, each AIR autonomously creates a link with the other memory fragment AIRs, and structures the memory fragments similarly to the human memory structure. The strength of the link used in this system is calculated from the similarity and time, place, content, etc., of the experience. Since an AIR autonomously establishes the relations, it becomes possible to manage the related information to deal with generation, update, and deletion of AIRs.

The process of structuring the link between the two AIRs is shown in Figure 5. Metadata information is exchanged between two AIRs to calculate the link strength. First, an AIR sends its own metadata as a link strength calculation request, immediately after the generation or update of the metadata. Upon receiving the metadata sent from the other AIR, each AIR calculates the link strength between the two AIRs according to the following Equation (1) based on its own metadata,

$$l = \alpha k + \beta t + \gamma p \tag{1}$$

where k is the keyword similarity, t is the time proximity, and p is the place proximity. α, β, and γ are the coefficients that determine the degree of influence of k, t, and p, respectively. The degree of similarity and the degree of proximity can be calculated by various methods. They need to be adjusted so that the value in case of perfect match is 1. They take values from 0 to 1. For example, the calculation methods shown in Table 4 are used. Equations for k, t, and p, according to the method shown in Table 4, are shown in Equations (2), (3), and (4) below.

$$k = tanh(K\ num) \tag{2}$$

$$t = \begin{cases} 1, & tA = tB \\ \tanh\left(\frac{T}{|tA - tB|}\right), & tA \neq tB \end{cases} \tag{3}$$

$$p = tanh(P/\sqrt{(lonA - lomB)^2 + (latA - latB)^2} \tag{4}$$

As shown in Equation (2), the keyword similarity k is calculated using the number of keywords matching between the two memory fragments. As shown in Equation (3), time proximity t is 1 if the time overlaps, otherwise it is calculated using the reciprocal of the time difference. The proximity of the locations shown in Equation (4) is calculated using the reciprocal of the distance derived from the latitude and longitude. Every value is normalized using a hyperbolic tangent at the end of the calculation, and it becomes the minimum value of 0, and the maximum value of 1. Each coefficient α, β, and γ can be changed according to the memory fragment, user's preference, and the purpose of use. They need to be set as the minimum value of 0 and the maximum value of 1. If the calculated value of l is greater than the specified threshold l^*, they are considered to be related, and the two AIRs hold the link and the information of the other AIR. When the AIR information is updated, the link strength is recalculated. Furthermore, when an AIR is deleted, it requests the deletion of the link information to the other AIRs that have a link with the deleted AIR.

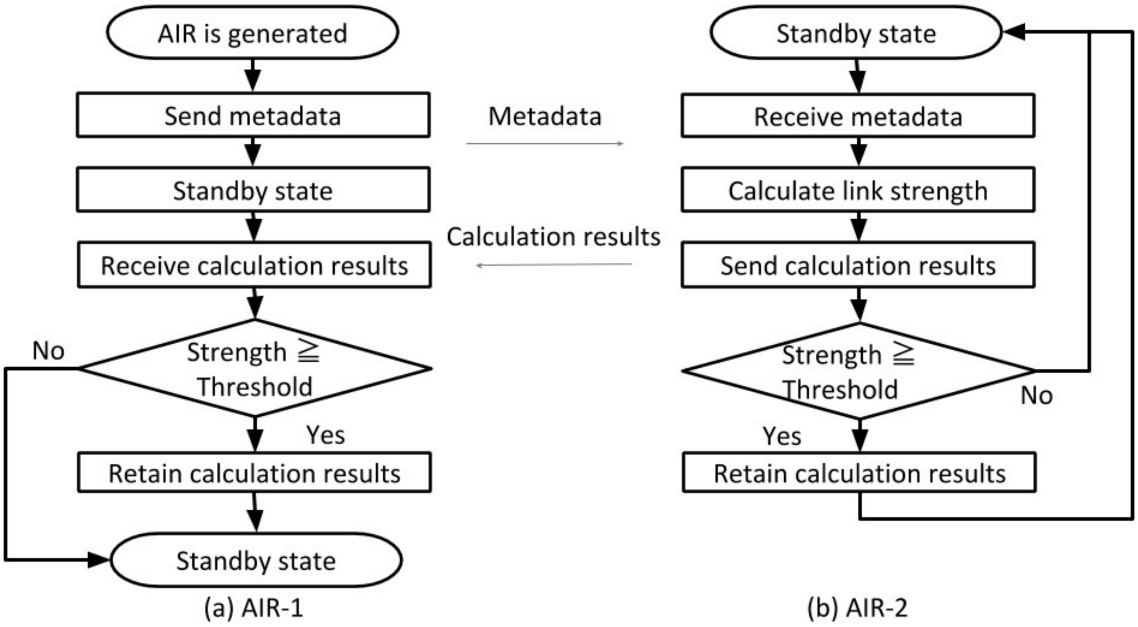

Figure 5. Flowchart of memory structure construction between AIRs.

Table 4. Example of deriving similarity and proximity between memory fragments A and B.

Name of Value	Calculation Method etc.	
Keyword similarity	Equation	$k = tanh(K\ num)$ (2)
	Meaning	K: Coefficient num: Number of matching keywords
	Range	$0 \leq k \leq 1$
Time proximity	Equation	$t = \begin{cases} 1, & tA = tB \\ tanh(T/\lvert tA - tB \rvert), & tA \neq tB \end{cases}$ (3)
	Meaning	T: Coefficient tX: The time when X was done (If there is a start and end time use a value close to the time of the other AIR)
	Range	$0 \leq t \leq 1$
Place proximity	Equation	$p = tanh\left(P/\sqrt{(lonA - lonB)^2 + (latA - latB)^2}\right)$ (4)
	Meaning	P: Coefficient ($lonX$, $latX$): The longitude and latitude of X
	Range	$0 \leq p \leq 1$

As a specific example of the link strength calculation, we describe the case of the two experiences shown in Tables 3 and 5: the seminar presentation and laboratory guidance. The AIR calculates keyword similarity based on Equation (2). If “Research”, “Institute”, “Electrical”, and “Communication” are matched, then $num = 4$, and $k = 0.01$, when $K = 0.025$. The proximity of time is calculated based on Equation (3). The times of the two memory fragments do not overlap. Therefore, let tA be the end time of laboratory guidance that is the event which first occurred. Also, let tB be the start time of the seminar presentation which is the event that happened later. In this case, if $T = 790{,}000$, then $t = 1.0$. Place proximity is calculated based on Equation (4). From the place information of two memory fragments, the distance is 0. In this case, if $P = 0.062$, then $p = 1.0$. Therefore, if the coefficients are $\alpha = 0.5$, $\beta = 0.35$, $\gamma = 0.15$, then $l = 0.51$. When the threshold $l^* = 0.1$, it is judged that there is a relationship between the seminar presentation and the lab guidance and the link strength information is held in the AIRs.

Table 5. Example of metadata used in an AIR (laboratory guidance).

No.	Name	Sub No.	Sub Name	Content
1	What	1-1	Title	Laboratory guidance
2	When	2-1 2-2 2-3 2-4	Start Time (JST) End Time (JST) Start Time (UNIX) End Time (UNIX)	20160404130000 20160404140000 1459742400 1459746000
3	Where	3-1 3-2	Address Coordinates	2-1-1 Katahira, Aoba-ku, Sendai 980-8577, JAPAN 140.87351675, 38.25326033
4	Content	4-1	Keywords	Laboratory, Guidance, Research, Institute, Electrical, Communication

3.2.3. Memory Structure Construction Function by Link Generation

This function autonomously searches AIR groups that satisfy the recall request of a user by using the knowledge and function possessed by the AIR and presents them as a chain of memories. For example, it is useful when the user wishes to recall the memories of past experiences but cannot recall the details. In the proposed system, the user can manually enter a part of the memory that the user recalled, such as keywords. It is also possible that the system automatically inputs the situation of the user.

Figure 6 shows the memory fragment recall process in an AIR. In this paper, a recall request is realized by a keyword-based input. The keywords are supposed to be related to the experience that the user wishes to recall. When a keyword is sent to each AIR, each AIR compares keywords with the metadata. If there is a matching metadata, that AIR is determined as a memory fragment to be recalled. Furthermore, in order to find the AIR related to the searched AIR, a calculation request is sent to the AIR that has a link with the searched AIR to execute a Knowledge Enhance Search [16]. In this search, the degree of relevance is calculated by tracing links starting from the searched memory fragments. The AIRs that did not match the recall request of the user are in a waiting state for a calculation request. When the request is received, the degree of relevance is calculated. The degree of relevance r is calculated using Equation (5). This is an index showing how much each memory fragment is related to the situation indicated by a memory fragment group.

$$r = tanh\Sigma w,\ w = \delta\ r'\ l\ m \tag{5}$$

δ is a coefficient that determines the influence degree of the link strength. r' is the degree of relevance of the calculation request source. l is the link strength between the AIR for calculating the relevance and the AIR for the request source calculated using the memory structure construction function by link generation. m indicates the number of times that the relevance calculation request was performed recursively. The number of iterations is limited by the threshold value m^*. If $m = 1$, then let $r' = 1$. In the proposed system, w is summated for each AIR. When the relevance, r, obtained by normalizing the total value exceeds the threshold value r^*, then the information is judged as the AIR with high relevance. At this time, if m is less than or equal to m^*, a calculation request is sent to the linking AIR.

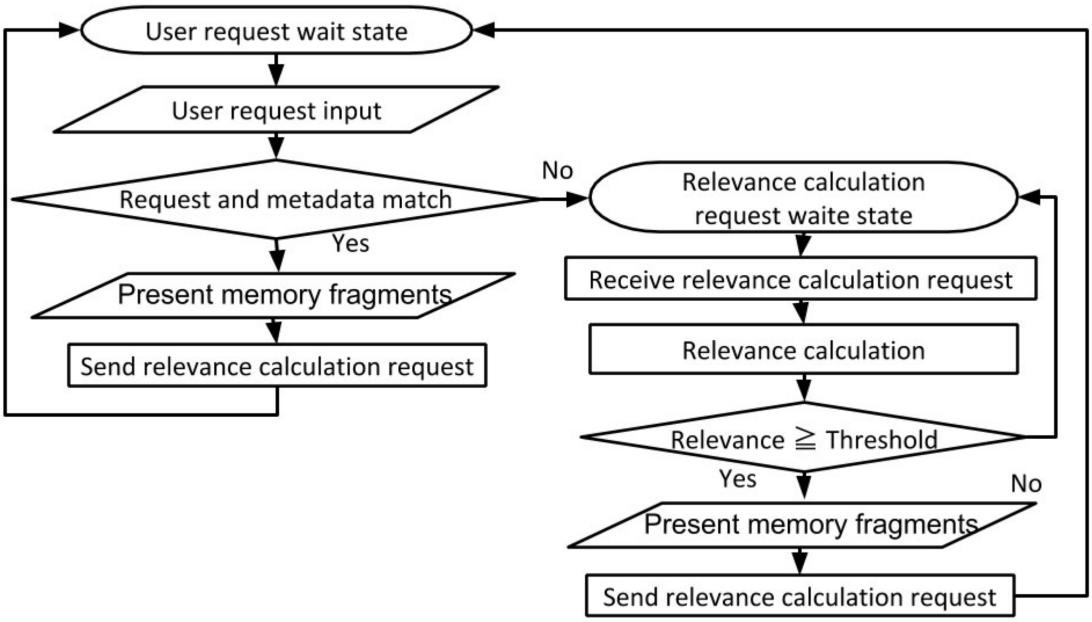

Figure 6. Flowchart of memory fragment recall in an AIR.

For example, if the AIR that manages the memory fragment of the seminar presentation shown in Table 3 matches the user's request, the AIR with the link, that is, the AIR of the laboratory guidance, calculates the degree of relevance. The link strength between the two AIRs is $l = 0.51$. Since the AIR of the laboratory guidance has direct relevance to the AIR of the seminar announcement, it receives a relevance calculation request at $m = 1$, $r' = 1$. If $\delta = 1$, then $w = 0.51$, and $r = 0.47$. If the threshold is $r^* = 0.1$, the AIR of the laboratory guidance is selected as the highly relevant AIR when the user refers to the seminar presentation AIR, and is presented to the user.

4. Implementation of the Proposed System

We describe the implementation of the memory recall support system proposed in the last section. The proposed system consists of a smartphone or tablet that users use for recording a memory fragment, and a Web server that hosts various services as shown in Figure 7. We prepared two interfaces: (i) the interface for memory fragment acquisition and activation; and (ii) the interface for a memory recall request and visualization of a provided memory structure. These interfaces are provided as a Web application that runs on the device of the user. AIRs are implemented as a multi-agent system operating on the Web server. The utilization support knowledge and utilization support function possessed by each AIR are realized as software agents. The metadata is held as the internal knowledge of the agent. The knowledge concerning the operation of proposed functions is represented in the knowledge of the agent.

As a software agent development environment, Java based agent development environment IDEA/DASH [17,18] was used. The knowledge in each agent is implemented using a rule-based agent programming language. Implementation of each proposed function is described below.

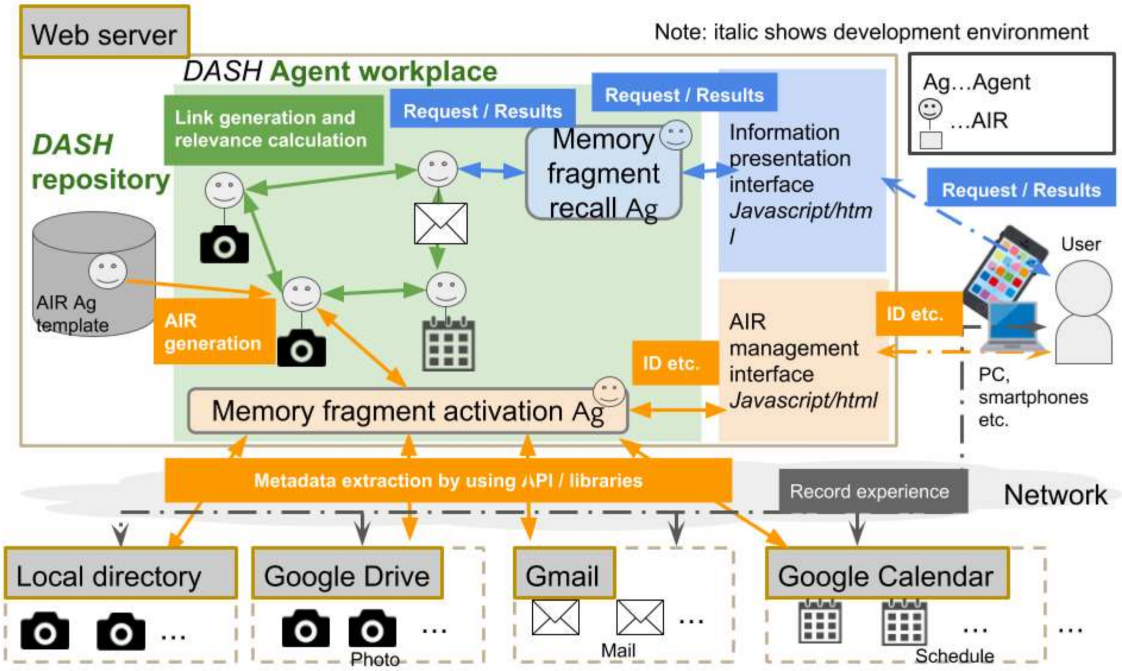

Figure 7. Implementation overview of the proposed memory recall support system.

4.1. Implementation of the Memory Fragment Activation Function Based on the AIR Concept (S1)

We implemented a manager of this function as a memory fragment activation agent as shown in Figure 7. In this agent, knowledge for memory fragment activation is implemented. Based on this knowledge, the agent acquires and converts the metadata of a memory fragment, and generates an AIR with the converted metadata.

APIs and libraries such as the Google Calendar API [19] are used for metadata acquisition. It is possible to extend the system to support various APIs in an uninformed manner. In order to deal with new memory fragments and updates, metadata acquisition is done regularly at 1-min intervals.

In metadata conversion, words included in sentences are acquired using morphological analysis in order to extract features from the content of the memory fragment and obtain keywords. To extract the content from the photograph, tags are acquired by image analysis. Geographical information is converted into the latitude and longitude format from address, name of place, and so on based on the implemented geographical information conversion function.

The creation of AIR is realized by replicating the AIR agent template, performed by the memory fragment activation agent. The knowledge possessed by the AIR agent is described in (2) and (3).

In acquiring metadata, in order to use APIs and libraries, and in order to specify the memory fragment to be acquired as AIR, information such as ID is often required. This type of information is used via automatic acquisition by the system or input by the user via the interface of Figure 8. This is an example of generating an AIR from the schedule of the user's Google Calendar. The user inputs the ID of the calendar, saving the schedule as an AIR, as shown in Figure 8a. Next, as shown in Figure 8b, a list of memory fragments are converted to an AIR and can be confirmed.

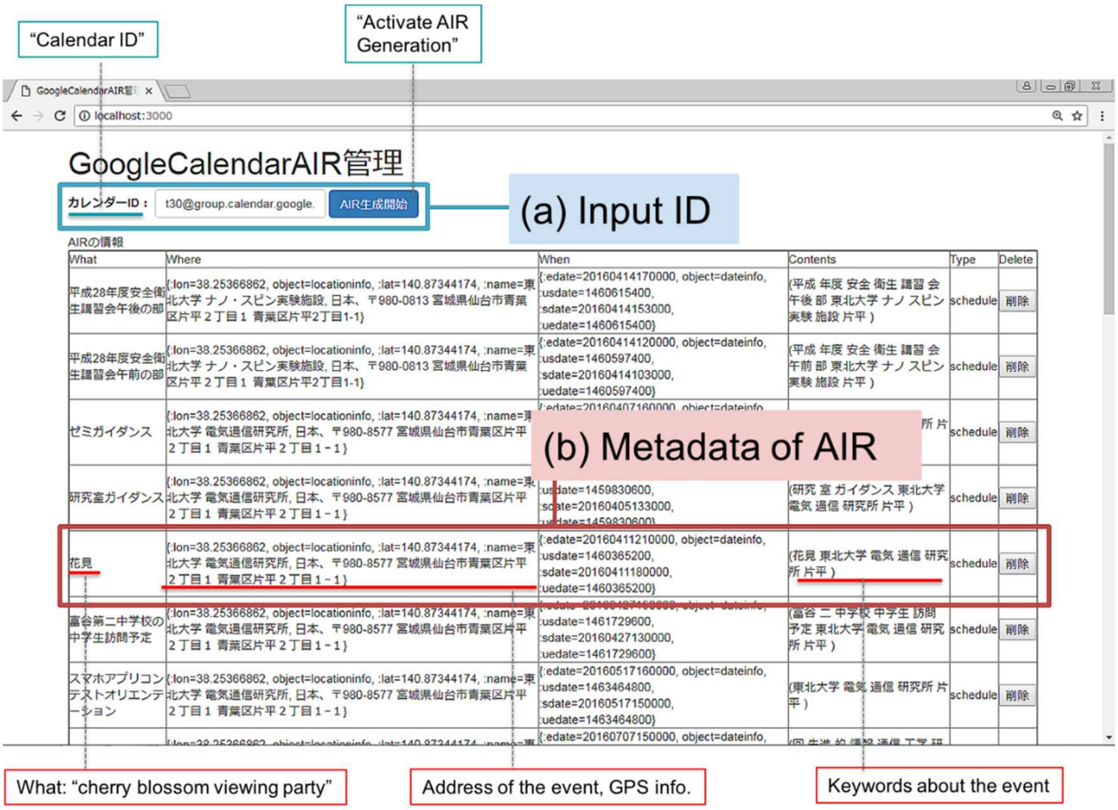

Figure 8. AIR management interface.

4.2. *Implementation of the Memory Structure Construction Function by Link Generation (S2)*

In order to realize this function, we implemented knowledge for link generation in all AIR agents. Based on this knowledge, the AIR agent sends its metadata to all the other AIR agents when it is created. Also, when receiving metadata from another AIR agent, it calculates the link strength and shares the result.

4.3. *Implementation of the Memory Fragment Recall Function by Cooperation of AIRs (S3)*

A manager that realizes this function is implemented as a memory fragment recall agent. In this agent, we implemented the knowledge for memory fragment recall. This knowledge acquires the recall request from the user, sends it to the AIR agents, and sequentially presents the information obtained from the AIR agents to the user.

We also implemented a method to calculate the relevance of each AIR agent. For this method, the agent confirms that it has received a recall request from the received user or a relevance calculation request from another AIR agent. Then, the relevance is calculated based on the request and according to the result, the relevance calculation request is sent, and the information is sequentially presented to the user.

For recalling memory fragments, it is necessary to obtain the recall request of the user and present the results to the user. An example of the interface is shown in Figure 9. In the information presentation of the proposed system, it is possible to present the memory fragment, which is useful for the memory recall support. In the system in this paper, as a presentation of information to users, we use a method to visualize the relevance of the memory fragment and the relevance to the user's request on a Web browser using an undirected graph.

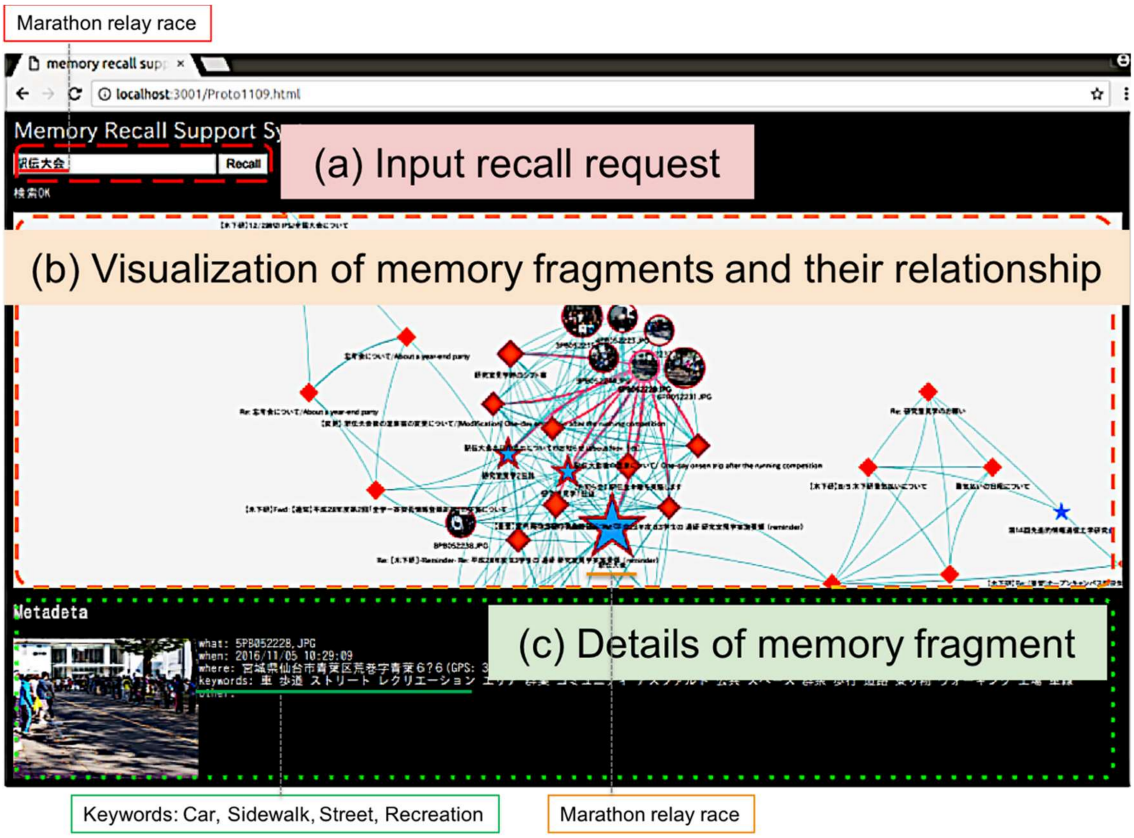

Figure 9. Information presentation interface.

In Figure 9a, a user's recall request is inputted and sent. In Figure 9b, all memory fragments and their relationships are displayed using an undirected graph. Each node of the graph shows an AIR, and is presented in a different shape depending on the type of memory fragment. A star type indicates a schedule, a round shape indicates a photograph, and a square indicates mail. The link between the memory fragments is visualized by connecting the nodes and the thickness of the link, which is dynamically changed in proportion to the strength. The system was implemented to display links as much as possible; to avoid hindering browsing due to a high concentration of links, the links between photos are hidden. This is done because the photographs are indirectly linked by schedule or e-mail, so that users can recognize the relationship. When the borderline of the node is emphasized in red, it shows that it is a memory fragment useful for recalling the recall request. When an AIR is selected, the link line of the AIR is emphasized as pink in color. Figure 9c is a space for displaying the memory fragment as content selected by the user. In this snapshot, the taken date, time, place, attached tag, and the enlarged photograph are displayed.

5. Recall Experiment and Evaluation of the Memory Proposed Recall Support System

5.1. Purpose and Overview of Experiments

Using the system implemented in the previous section, we try to experimentally confirm that the technical problem described in Section 2 is solved by the proposed functions (S1, S2, and S3), and the effective memory recall support system is realized. We conducted the following two experiments.

Experiment 1: Experiment of acquiring, accumulating and providing memory fragments

In Experiment 1, a graduate student is the user, and the usefulness of each function of the proposed system is evaluated, that is, we confirm that the following three points have been achieved.

1. Acquisition of memory fragments of the user's experience and the conversion of memory fragments into AIRs that can be used in the system
2. Autonomous association of memory fragments
3. Memory structure construction based on an AIR driven by the user's request, and the memory structure presentation functionality to the user

Therefore, we confirm that the proposed system can acquire the user's memory fragment and structure the experience.

As a memory fragment, a total of 322 memory fragments related to major events occurring in a laboratory in the term 1 April 2016 to 30 March 2017 were introduced in the experiment, as follows:

- 38 schedules entered into Google Calendar
- 122 photos on the shared file directory hosted in a PC
- 162 e-mails saved in Gmail

The reason for using the above three kinds of memory fragments in this experiment is because generally people accumulate these memory fragments on a daily basis. We confirm the operation and effect of each proposed function by confirming the operation of the proposed system using these 322 memory fragments.

Experiment 2: Recall experiment by the user

In Experiment 2, six graduate students are the users, and we confirm the usefulness of the proposed system. By using the proposed system, we examine

- the accuracy,
- level of detail,
- and speed,

of recalling information about past experiences. We conducted an experiment of answering questions and describing information about the experience freely within the time limit. We also conducted questionnaires to investigate the user's feelings about using the proposed system. Experiment 2 was performed using 322 memory fragments prepared in Experiment 1. We confirm the effect of the proposed system by actually recalling information using the system.

We describe the coefficients and threshold values of various calculation formulas in experiments and their setting methods. Table 6 shows each coefficient and threshold value in this experiment and the setting criteria.

In this system, values k, t, and p in Equation (1) are derived by the method shown in Table 4. For each coefficient, K, T, and P, the values shown in Table 6 were set. We explain the setting policy of this coefficient using the case of K. The intermediate value is derived from the minimum value and the maximum value of the keyword matching number between all memory fragments, and $K = 0.025$, which is $k \approx 0.1$, when *num* is the intermediate value. This is because when the number of matched keywords is equal to an intermediate value, k is set to a small value that does not substantially affect the link strength.

For the coefficients α, β, and γ that determine the degree of influence of k, t, and p, it is necessary that the sum of three coefficients is 1 in order to make the maximum value of l equal to 1. In this example, $\alpha = 0.5$, $\beta = 0.35$, and $\gamma = 0.15$. This is because the amount of metadata possessed by the introduced memory fragment is large in the order of keywords, time, and place, and the difference detected from these metadata should be reflected in the link strength.

Table 6. Coefficient and threshold used in the experiments.

Coefficient/Threshold	Meaning of the Value	How to Set the Value (s)
$\alpha = 0.5$	Coefficient that determines the degree of influence of the keyword similarity	$\alpha + \beta + \gamma = 1$, which are balanced according to the amount of metadata.
$\beta = 0.35$	Coefficient that determines the degree of influence of the time proximity	
$\gamma = 0.15$	Coefficient that determines the degree of influence of the place proximity	
$K = 0.025$	Coefficient for adjustment of keyword similarity	K is set to make the similarity approx. 0.1 when the number of keyword matches is the intermediate value.
$T = 790{,}000$	Coefficient for adjustment of time proximity	T is set to make the proximity approx. 0.1 when the time difference is the intermediate value.
$P = 0.062$	Coefficient for adjustment of place proximity	P is set to make the proximity approx. 0.1 when the distance is the intermediate value.
$l^* = 0.34$	Threshold of link strength l	l^* is set to make the number of links of one AIR 50 or less.
$\delta = 1$	Coefficient that determines the degree of influence of the link strength	These are set to make the calculation time for one recall request approx. 30 s or less.
$r^* = 0.3$	Threshold of relevance r	
$m^* = 3$	Threshold that represents the number of performed relevance calculations	

Also, $l^* = 0.34$ was set so that the maximum number of links of one AIR was 50 or less. This is to prevent the user's waiting time from becoming too long when calculating the degree of relevance according to the user's request.

In this system, coefficient δ and thresholds r^* and m^* of Equation (5) are set as shown in Table 6. In order to present the results in less than 30 s for one recall request, several recall experiments were attempted, and $\delta = 1$, $r^* = 0.3$, and $m^* = 3$.

Since the information presentation in response to the recall request is performed sequentially from the memory fragment first judged to be useful for recalling, it is possible to browse the first memory fragment in approximately 1 s after the recall request.

The results and considerations of Experiments 1 and 2 and the summary of the experiment will be described below.

5.2. Evaluation of Usefulness of Each Function

Using the results of Experiment 1, we evaluate the usefulness of each function in the proposed system.

5.2.1. Evaluation of Memory Fragment Activation Function Based on the AIR Concept (S1)

(1) Evaluation of Memory Fragment Acquisition/Conversion

We confirm that a wide variety of the user's memory fragments can be captured and used by the memory fragment activation function (S1) based on AIR. Three kinds of memory fragments—schedule, photograph, and mail—were targeted for acquisition as an AIR using the AIR management interface. As a result, 322 memory fragments were prepared properly in this experiment.

Figure 10 shows the result of generating AIRs of memory fragments about the user's one-day experience. Figure 10 shows the schedule of the event performed on this day, the email related to the event sent on this day, and 22 pictures taken during the user's events. Even if they are heterogeneous resources, the memory fragments are gathered together as shown in Figure 10, and became available on the unified interface.

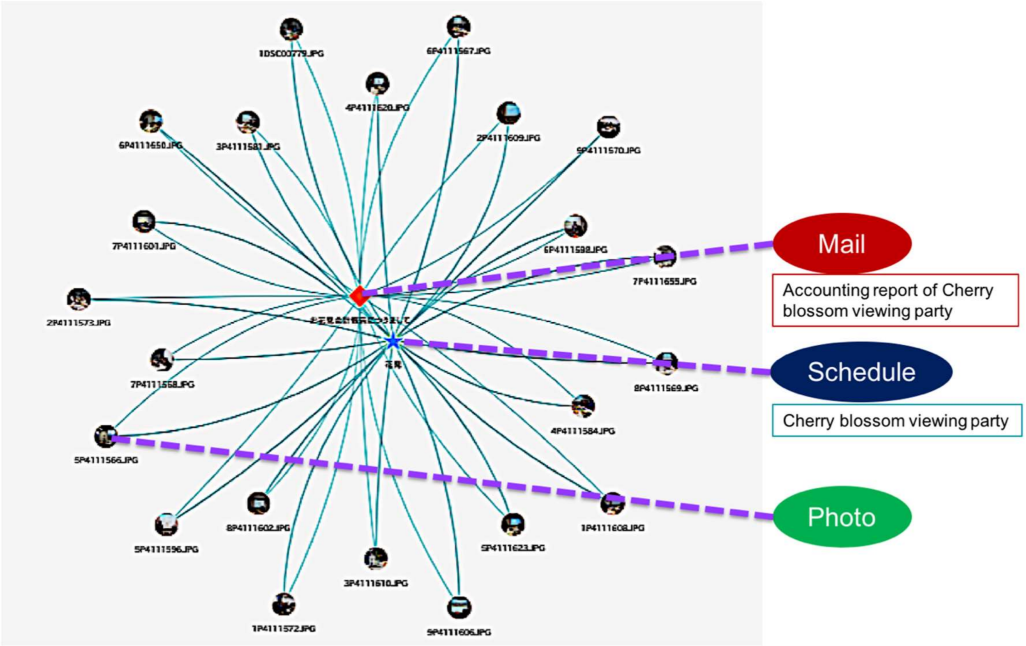

Figure 10. Presentation results of the memory fragments from one day of user experience generated as AIRs.

Figure 11 shows the results of acquiring one year of memory fragments from 1 April 2016 to 30 March 2017. In this result, 322 memory fragments can be used, which indicates that all the memory fragments to be targeted in this experiment became available. In addition to the 24 memory fragments shown in Figure 10, other memory fragments also became available on the same interface. It can be seen that different memory fragments are associated with each other as necessary.

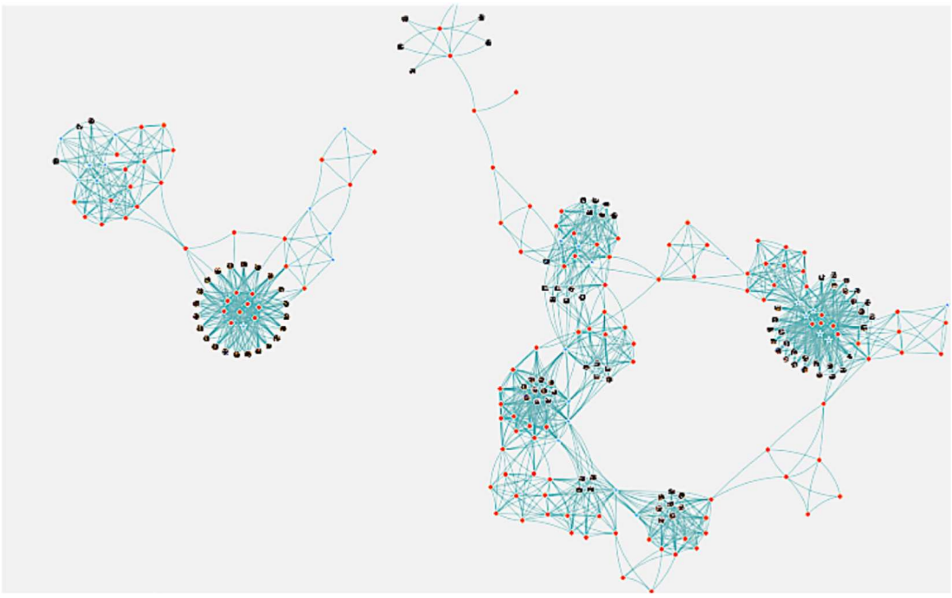

Figure 11. Presentation results of memory fragments from one year of user experience (1 April 2016 to 30 March 2017) generated as an AIR.

From these results, it is confirmed that a wide variety of memory fragments related to the user's experience can be used in a unified manner.

(2) Evaluation of Time Required for Memory Fragment Activation

This function enables the system to automatically perform the structuring of the memory fragment. In order to confirm that this function reduces the burden on users and that the operation of the system is sufficient for practical use, the execution speed of the process that generated the memory fragment as an AIR was measured.

First, we measure the time taken when the user manually creates an AIR. The schedule is used in this experiment because it contains information on time and place, sentences for extracting keywords indicating content, and it is possible to perform the conversion process manually. In the case of manual work, a user browses the specified schedule in Google Calendar, extracts information based on the metadata format of the AIR, and enters it into the template file. Five schedules were targeted, and metadata extraction and conversion were performed once for each schedule manually, and the average time taken was calculated. As a result, it took an average of 206.2 s for one schedule. In this system, which is expected to use a large number of memory fragments, the method, which takes several minutes to generate one AIR, is not practical. It is a heavy burden for the user to manually perform these tasks.

The function of memory fragment activation automates the AIR generation process and reduces the time and effort required. Therefore, when the system automatically generates an AIR, we check whether the time to extract and convert the metadata is sufficiently short and it is possible to handle a large number of memory fragments. For each of the five schedules used for calculation in the case of manual work, AIR was generated five times using the proposed system. The average time taken for one operation was calculated to be 0.67 s. Therefore, by using the proposed system, the time has been greatly shortened compared to manual work. It is possible to generate about 300 memory fragments as an AIR within the time that a single memory fragment is generated manually as an AIR.

From the above results, it was confirmed that the introduction of this function can reduce the burden caused by users having to input and accumulate information.

5.2.2. Evaluation of the Memory Structure Construction Function by Link Generation (S2)

We confirm that links were autonomously built among memory fragments by this function. Figure 12 shows connections among the memory fragments centered on a party (cherry blossom viewing party) conducted in the laboratory. This association was made automatically as soon as the memory fragment was generated as an AIR.

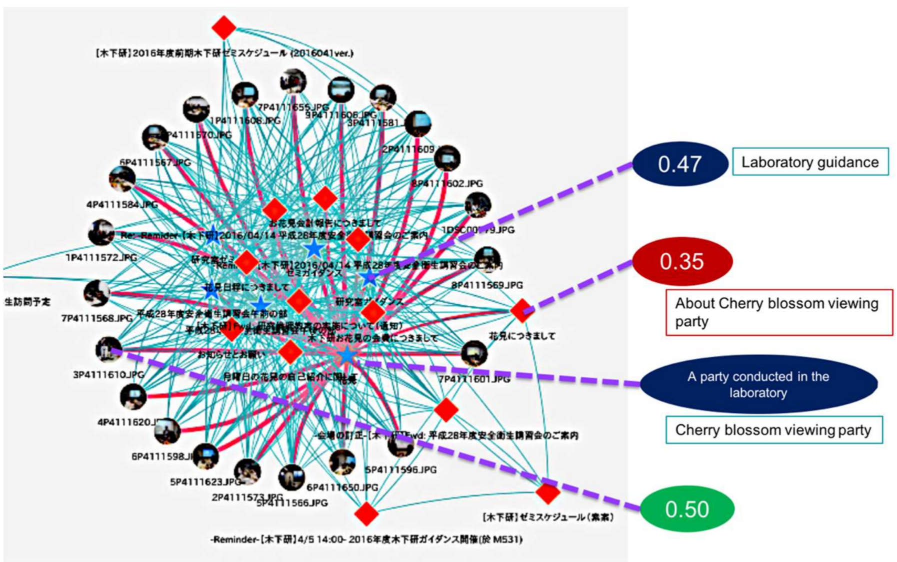

Figure 12. Result of the memory structure construction centering on the schedule of a party (Cherry blossom viewing party).

Examples of a memory fragment having a strong link with this party schedule are shown in Figure 12. For example, a certain photograph taken during a party has a link strength of 0.50 because the date and time are close to each other. In addition, the mail related to the party sent five days before the party was close to the date and time, and the content was similar, so the link strength was 0.35. In addition, the schedule of laboratory guidance that seemed not to be related to the party was also similar in both date and time, and was held at the same place, so the link strength was 0.47.

From these results, it was confirmed that the memory fragments relating to the same experiences, and the memory fragments having similar time, place, and content were automatically correlated. In other words, we confirmed that a link can be constructed autonomously by information exchange and the calculation function of this function.

5.2.3. Evaluation of the Memory Fragment Recall Function by Cooperation of AIRs (S3)

(1) Qualitative Evaluation of the Construction and Presentation of the Memory Structure Driven by User Request

First, we confirm the operation of the system, incorporating the proposed function. Based on the user input of keywords to recall an experience, it is necessary to confirm that the memory fragments related to the experience the user wishes to remember are presented by this function.

An example of recall experience is the "cherry blossom viewing party". The user has a request that he/she wants to recall information such as the day, place, preparation for the event, and the feelings of the day about the party.

Therefore, the user inputs the keywords "cherry blossom viewing party" to the information presentation interface as a recall request. As a result, the memory fragments that are useful for recalling are emphasized with a red borderline as shown in Figure 13.

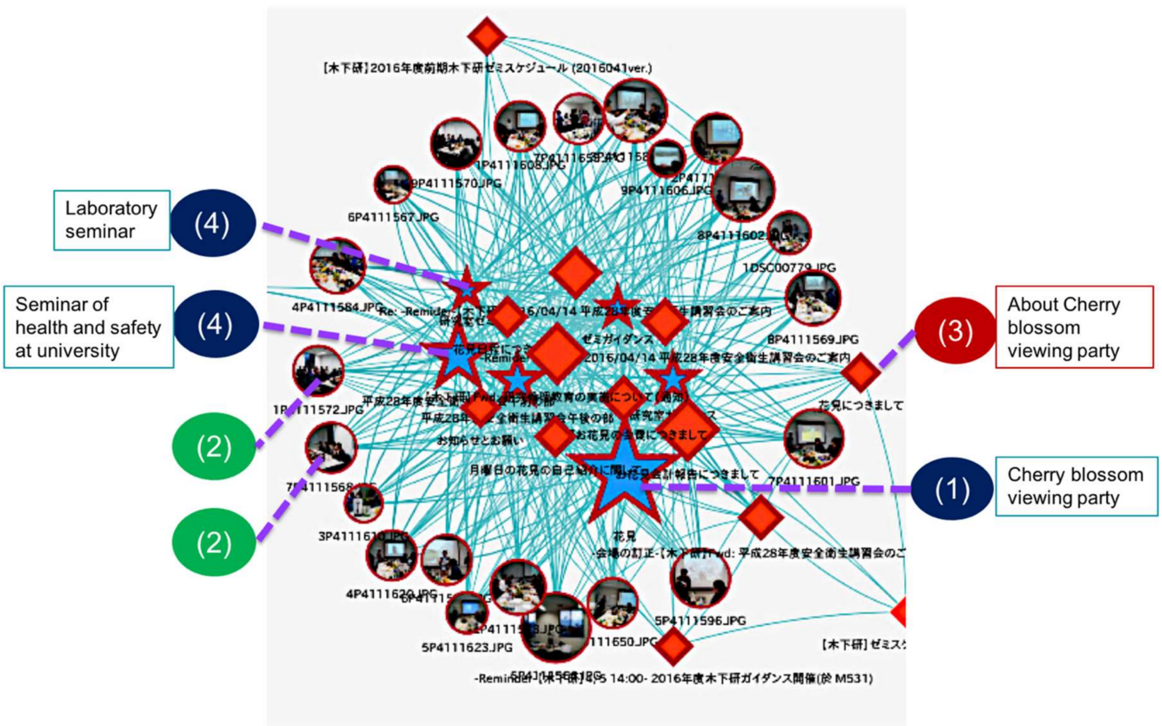

Figure 13. The results of a recall request for "cherry blossom viewing party".

(1) Figure 13 shows a schedule of the "cherry blossom viewing party", and memory fragments to be recalled are presented centering on this memory fragment. By viewing (clicking on) this schedule,

the user can recall basic information of the "cherry blossom viewing party". Presented (2) in Figure 13 is a picture of the party, which is helpful for the user to recall the scene of the event. (3) Figure 13 shows mail related to the party, which can help to recall the attendance fee and schedule adjustment. Figure 13 (4) is an event held around the "cherry blossom viewing party". These remind the user that the party was an event in a new semester. These memory fragments also helped to recall situations where the user attended the meetings with new members on a day close to the event.

In this way, we confirmed that memory fragments that support recall are presented in response to the recall request entered by the user.

(2) Quantitative Evaluation of the Construction and Presentation of the Memory Structure Driven by the User Request

We quantitatively evaluated whether the information presented by this function is useful for recalling. In this experiment, we confirmed that it is possible to present the memory fragment, which could not be recalled using the existing system.

We confirmed that this function makes it possible to determine effective memory fragments for recall in response to the user's request. In this experiment, we evaluated how many useful memory fragments are presented for three recall requests. We define the existing system as a user search based on recall request keywords using Google Calendar, Gmail, and Windows Explorer. We make a comparison between the existing system and the proposed system. In addition, when the recall is insufficient, only with the memory fragment matching the keyword, the user can re-search using information such as the time, place, content, etc., of the memory fragment that were presented in the first search.

For memory fragments prepared for a recall experiment, a system user browses all the memory fragments and classifies them based on the following conditions:

- The experiences of the recall request itself are shown
- There is a high degree of similarity with the content of the experiences of the recall request
- It is possible to connect memories to fragments because the date and time of the memory fragment are close to the experiences of the recall request (before and after 1 month)
- The place of the memory fragment is close to the experiences of the recall request (before and after 1 month)

When using the existing system and the proposed system, we calculated the *precision*, *recall*, and *F-measure* of the memory fragment presentation. The *precision*, *recall*, and *F-measure* were calculated by the following Equations (6), (7), and (8).

$$Precision = <\textit{Number of correct and presented memory fragments}> / <\textit{Number of presented memory fragments}> \tag{6}$$

$$Recall = <\textit{Number of correct and presented memory fragments}> / <\textit{Number of correct memory fragments}> \tag{7}$$

$$F\text{-}measure = (2 \times precision \times recall) / (precision + recall) \tag{8}$$

Table 7 shows the results of calculating the *precision*, *recall*, and *F-measure* using the presentation results recalled for three patterns of recall requests using each system. The number of presented memory fragments has increased from 5 to 10 times in the case of the proposed system compared to the existing systems. We evaluated the results in order to confirm that the proposed system presents more necessary items and not unnecessary items.

Table 7. Results of the calculation precision, recall, and F-measure.

No.	Type of System	Number of Correct Memory Fragments	Number of Presented Memory Fragments	*Precision*	*Recall*	*F-Measure*
1	Existing	42	8	1.00	0.19	0.32
	Proposed	42	40	1.00	0.95	0.98
2	Existing	34	3	1.00	0.09	0.16
	Proposed	34	31	0.48	0.91	0.63
3	Existing	43	7	1.00	0.16	0.28
	Proposed	43	32	0.97	0.74	0.84

First of all, we describe the precision, indicating how many of the memory fragments are useful for recalling. The *precision* was higher in the existing system for the two types of recall requests and was the same for one type of recall request. This is because the existing system presents only the memory fragments explicitly including the keyword of the recall request, so it is unlikely to present an incorrect memory fragment. In the proposed system, although the date, time, and place are similar values, it is not possible to determine if a memory fragment is useful for recalling by the user, so the *precision* is low.

Next, the *recall* showing the coverage of how many of the memory fragments are useful for recalling was higher in the proposed system for all three recall requests. This is because the existing system cannot present memory fragments which do not include the recall request keyword even if they are useful memory fragments, but in the proposed system memory fragments can be presented using the dates, times, places, and content links.

The *precision* and the *recall* exist in a trade-off relationship. Therefore, we calculated the *F-measure* as a comprehensive evaluation and confirmed that the proposed method is higher for all three requests. It was confirmed that the accuracy of the recall, supported by the proposed function, is higher than that of the existing system.

From the above, it can be said that the memory fragment recall function enables the presentation of various memory fragment groups with reasonable relevance to the user's recall request with little effort.

5.3. Evaluation of System Utility

In Experiment 2, we asked users to recall using the actual memory recall support system, and confirmed the effect. The users were six graduate students (four master's degree students and two doctoral degree students) from the same laboratory. This means that the users in our evaluation share common experiences which are related to the same memory fragments, e.g., photographs of a party that everyone attended, the schedule information of a particular laboratory event, etc., as shown in Figure 14.

The experiment was conducted between 11 and 14 November 2017 using 322 memory fragments concerning experiences that occurred from 1 April 2016 to 30 March 2017. These memory fragments contain 38 events, and the questions that were presented in the experiment concern these events. Since all of the users participated in all of these events, these memory fragments would support each user's own memory.

In this experiment, we conducted experiments using 322 memory fragments that became available in Experiment 1. These 322 memory fragments are known information for all users, and in Experiment 2, all users conducted experiments using these memory fragments. For all users, these 322 memory fragments dealt with experiences that occurred in their laboratories in the period during which they shared experiences. Therefore, they can be regarded as shared memory fragments and can be used for recall support.

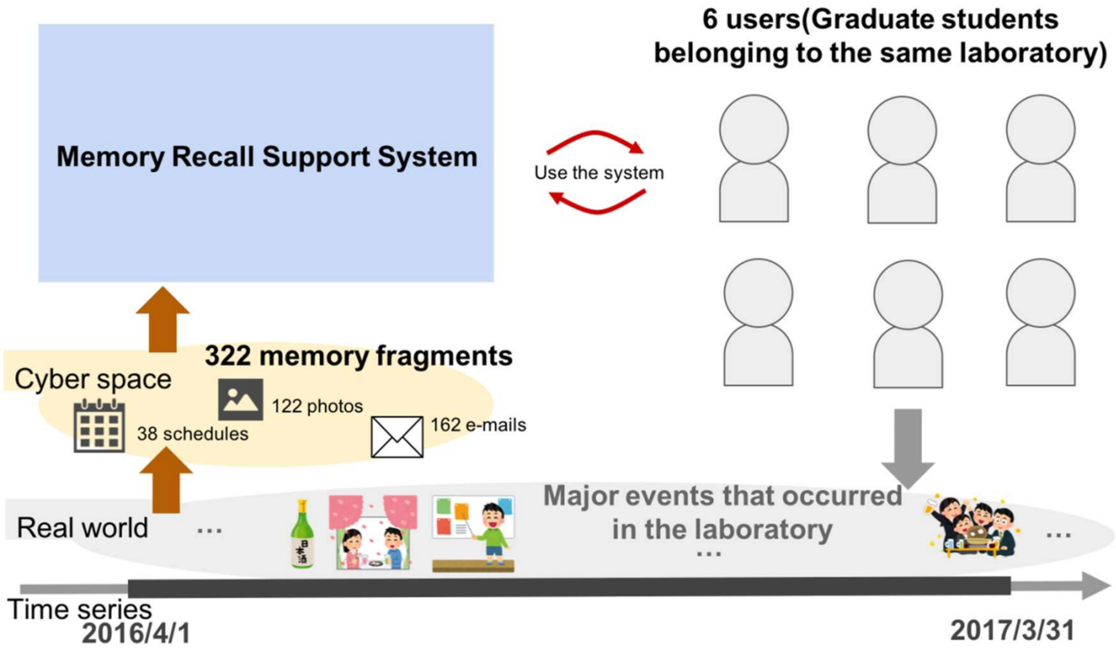

Figure 14. Users and events in experience 2.

As a comparison with the proposed system, we define the existing system as the combination of the search functions of Google Calendar, Gmail, and Windows Explorer. In the existing system, the same 322 memory fragments are usable.

Using the proposed system and the existing system, the degree of recalling was confirmed by the following three experiments.

- **Experiment 2-1**: Evaluation of recall support efficiency based on the percentage of questions answered correctly, and the response time of answering to past experiences
- **Experiment 2-2**: Evaluation of the efficiency of multilateral recall support based on the percentage of questions answered correctly, and the response time of answering to past experiences
- **Experiment 2-3**: Evaluation of the level of detail and number of recalled episodes
- **Questionnaires on Experiments 2-1, 2-2, and 2-3**: After the above three experiments, we conducted questionnaires about the convenience of the existing system and the proposed system, and the degree of recall support efficiently

The details, the results of Experiments from 2-1 to 2-3, and analysis of the results are described below. In addition, the results of the questionnaire on the system at 5.3.4 and the summary of the experiment 2 at 5.3.5 are described.

5.3.1. Experiment 2-1: Evaluation of Recall Support Efficiency Based on the Percentage of Questions Answered Correctly, and the Response Time of Answering to Past Experiences

In this experiment, we asked six users the same 10 questions. For each question, we designated three users who answered using the existing system and three users who answered using the proposed system. Therefore, six users answered five questions using the existing system and five questions using the proposed system, and the allocation of questions differed among all users; this was to eliminate the bias due to individuals' familiarity with the system and the experience.

Table 8 shows the questions that were presented in this experiment. To protect privacy, experience name, person name, and place name are hidden in this paper, but in the experiment we used the real names. These questions could be answered by browsing the appropriate memory fragments.

For all 10 questions, the correct answer rate using the existing system was 100%, and the correct answer rate using the proposed system was 93.3%. The reason why the proposed system answer rate was not 100% was that two out of 30 questions were incorrect. One incorrect answer was due to the ambiguity of date specification, i.e., the definition of "a week" in question 8; as no explanation was given to the user that "a week means exactly 7 days", the user answered with a 6-day experience (about a week). Another incorrect answer was due to a misinterpreted question (question 7); the name of the lecture was answered instead of the name of the speaker. Based on these results, we confirmed that if the users understood the question correctly, accurate recall could be performed using either the existing system or the proposed system.

Table 8. Content of the questions that were presented in Experiment 2-1.

ID	Content
Q1	What is the attendance fee for Experience A?
Q2	Where is the room where Experience B was held?
Q3	Who is the guest of Experience C (1 person)?
Q4	What did you eat in Experience D (1 dish)?
Q5	Who handed the gifts to the guests at Experience E?
Q6	Who was the person sitting by the window and also sitting in the front row during Experience F?
Q7	Who was the speaker of the experience three days after Experience G?
Q8	What was the experience that took place (exactly) one week after the seminar where person A participated?
Q9	At what time was the watermelon cut in Experience H?
Q10	When was the application deadline of the event that was held at location A?

From the time it took to answer 10 questions, the average time taken to answer a question is shown in Figure 15. The average time using the existing system was 87.0 s, and the average time using the proposed system was 75.6 s.

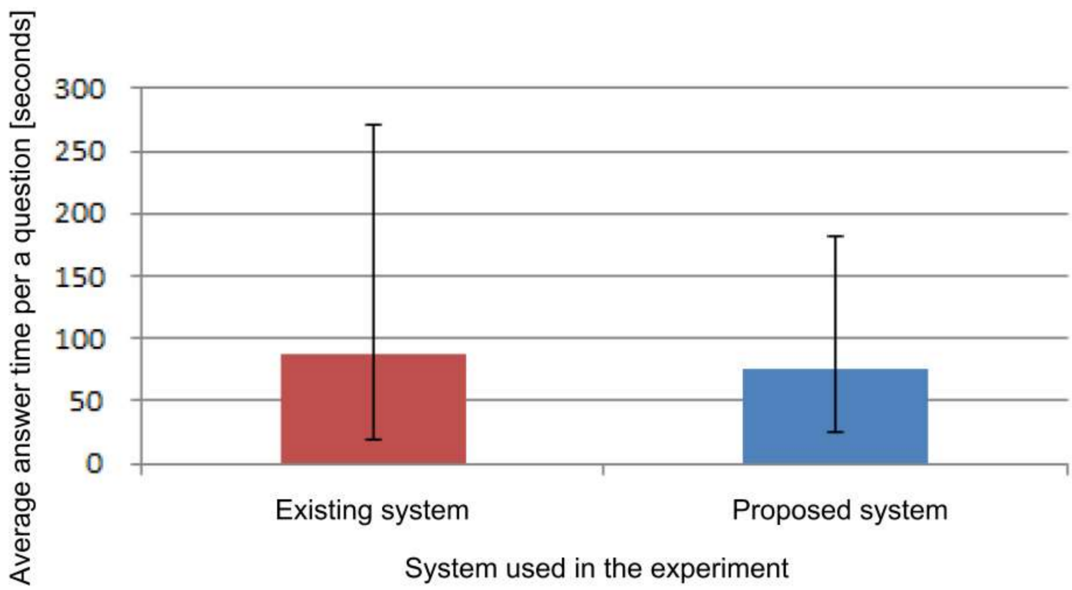

Figure 15. Average answer time per question for all 10 questions in Experiment 2-1.

For each of the 10 questions, the average times using the existing system and the proposed system are shown in Figure 16. Two of the ten questions were answered in a shorter time using the existing system. Seven questions were answered in a shorter time using the proposed system. The relationships between the features of each question and the characteristics of the system are described below.

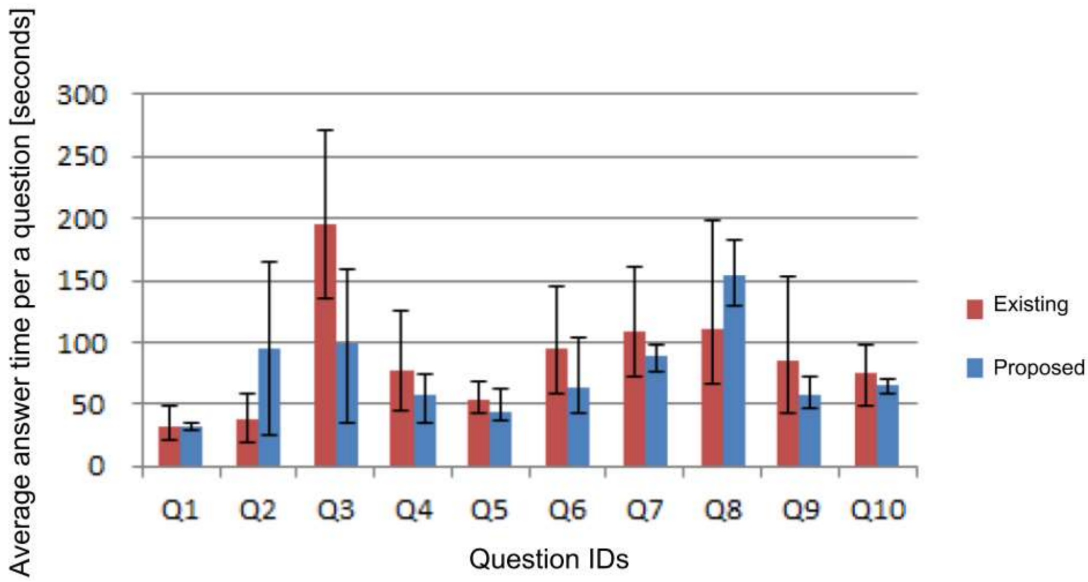

Figure 16. Average answer time per question in Experiment 2-1.

Case where users can answer in the same amount of time using either system (Q1)

When there is one memory fragment to be viewed for answering and it is easy to find, there is almost no difference in recall time between the existing system and the proposed system.

In order to answer Q1, it was necessary to view an email (titled "About membership fee of experience A"), which informs members about the fee of the recall target experience A. When using the existing system, users decided to search for emails in Gmail and could use the corresponding mail by searching "Experience A", "Membership Fee", or a combination thereof. When using the proposed system, the users gave a recall request "Experience A"; they found the corresponding email based on the presented result and could use it.

Cases where users can answer quickly using the existing system (Q 2, 8)

When it is necessary to narrow down the appropriate memory fragment from a large number of memory fragments with similar characteristics, it is easier to answer using the existing system.

For example, in question 2, there is a large number of memory fragments related to experience B; by searching for a certain email from these memory fragments, the user could find a room name (answer) written in the content. When using the existing system, the users were able to narrow down by keywords "Experience B", "Room", or "Place" using the search engine, and could answer. On the other hand, in the proposed system, several memory fragments were presented at once, but the title of the email did not include the room name or it was written in the email itself. As a result, it was not easy to find a memory fragment that contained the information necessary to provide an answer simply by checking the email titles. In the implementation of this proposed system, when searching for a memory fragment that matches the recall request, only the memory fragments with the metadata exactly matching the input word were searched. Therefore, it was difficult to narrow down the options compared to the search engine of the existing system.

Thus, in cases where narrowing down a large number of memory fragments is required in order to extract a certain memory fragment, it is sometimes possible to recall a memory in a short time using the existing system. The response time of the proposed system can be greatly shortened depending on the improvement of the search engine.

Cases where users can answer quickly using the proposed system (Q3, 4, 5, 6, 7, 9, 10)

In cases where users using the proposed system can answer quickly, there is a common point: It is necessary to view multiple memory fragments to answer a single question. As an example, one question asks what a user ate in an experience (Q4). In the existing system, it is necessary to recall the time of the specified experience using Google Calendar, and search the photo corresponding to that time using Windows Explorer. Using the proposed system, when the name of a designated experience is entered as a recall request, relevant photos taken during that time are presented, so it was possible to answer with fewer steps.

Even when it is difficult to judge which type of memory fragment is necessary for answering it is possible to answer in a short time using the proposed system. For example, in question 3, in order to answer the name of a guest participant, it is necessary to view the photograph. However, in the first step, one could think that there is information in the email, and in the case of using the existing system, it was possible to conduct a search using various search words. By using the proposed system, users can browse related memory fragments. As a result, memory fragments of the type that do not contain guest information will not be browsed, thus shortening the time required to answer the question.

As described above, when the number of searches increases in the existing system or a search needs to be performed using multiple search systems, it is often possible to shorten the response time by using the proposed system. This is because there is no need to move windows and tabs, and the connection between memory fragments including heterogeneous intervals can be used. It is also because thinking time is reduced regarding, for example, which search word to use, which search system to use and how long to search.

From these analyses, it was confirmed that accurate recall can be achieved using the proposed system. In addition, it was confirmed that it is possible to shorten the recall time, especially when it is necessary to view multiple memory fragments for answering a single question. This is because the necessary, relevant memory fragments are presented.

5.3.2. Experiment 2-2: Evaluation of the Efficiency of Multilateral Recall Support Based on the Percentage of Questions Answered Correctly and Response Time to Past Experiences

In Experiment 2-2, questions were presented to users and the correct answer rate and response time were measured. In this experiment, unlike Experiment 2-1, we asked five questions related to the same experience and measured the total response time. We confirmed that the time required to recall from various perspectives of one experience can be shortened.

In this experiment, two events were presented as recall targets. Both of these events were parties organized at the laboratory to which the users belong; the number of participants and the length of the party are similar. The number of photographs taken during the party, and the number of emails including party names are also similar. In addition, all six users participated in two events.

Six users were divided into group A and group B. When answering the question about the first event, group A used the existing system and group B used the proposed system. For the second event, group A used the proposed system and group B used the existing system. This is to eliminate bias due to individuals' familiarity with the system and the events.

The questions (common for the two events) that were asked in the experiments were as follows:

- Date of the event
- Place of the event
- Time when people toasted at that event
- The organizer of the event
- What was done at that event

The correct answer rates when answering the questions related to the event using the existing system and the proposed system were both 100%. As shown in Figure 17, the average response time was 230.33 s when using the existing system and the average was 110.17 s when using the proposed system. In addition, when a t-test with a significance level of 5% was applied to the response time value, the t-value was 4.771 and the p-value was 0.005, which means that there was a significant difference. From these results, we confirmed that, using the proposed system, accurate information can be recalled in a shorter time compared with the existing system when multiple types of information are recalled for one experience.

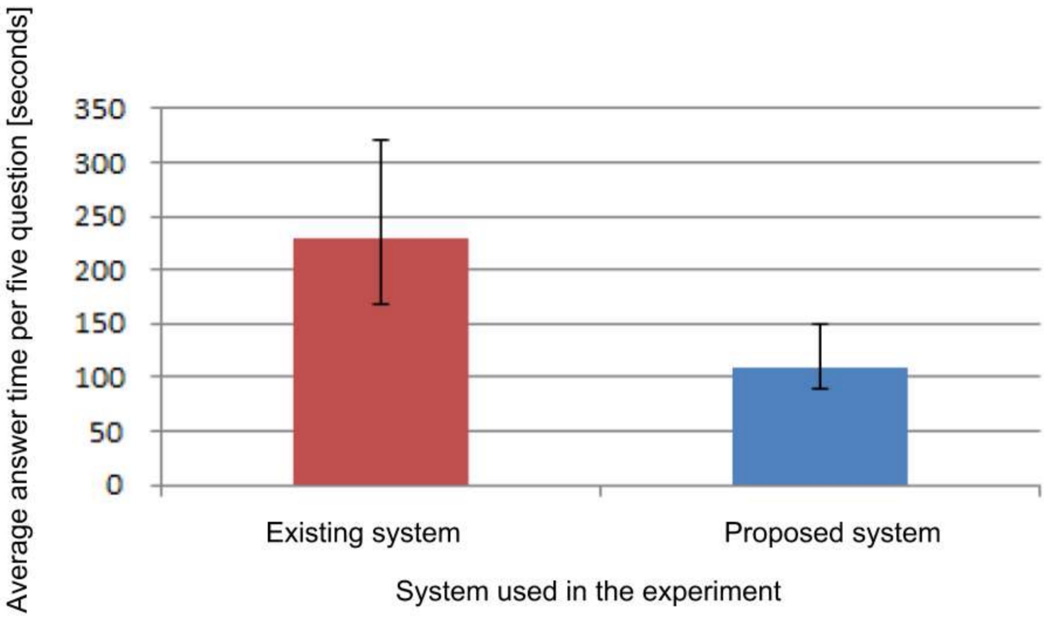

Figure 17. Average time taken to answer five questions on one event in Experiment 2-2.

5.3.3. Experiment 2-3: Evaluation of the Level of Detail and Number Recalled Episodes

In Experiment 2-3, we presented the event name to the users and asked them to describe the result of recalling the experience. By measuring the number of recalled episodes, we confirmed that detailed recalling becomes possible when using the proposed system.

The events which were presented in this experiment are the same as the two experiences used in Experiment 2-2. Also, the grouping of six users and the systems they use are the same as in Experiment 2-2.

In this experiment, the users recalled episodes within the time limit for the designated event, and the recalled episodes were described in detail each time. We instructed the users to write everything they recalled, including information directly related to what happened at the designated event, and information on different experiences associated with it. The users were instructed to describe the recalled episodes as a sentence including nominatives and predicates. The users tried to write one piece of information in one sentence, but if this was difficult and time-consuming, they wrote all information in one sentence. Therefore, after the experiment, the sentence was divided according to a certain criterion.

Before recalling using the existing system and the proposed system, we asked users to describe the episodes which could be easily recalled by oneself. This was in preparation for eliminating bias due to the difference in ease of recalling each event. After finishing the self-recall, we set a time to recall the episodes using the system and described it for 15 min.

The result of the number of episodes when using each system is shown in Figure 18. The amount of self-recalled episodes was not counted. The average number of episodes when using the existing system was 13.83 and the average when using the proposed system was 21.17. From these results, it was confirmed that by using the proposed system, it is possible to quickly recall one experience in detail.

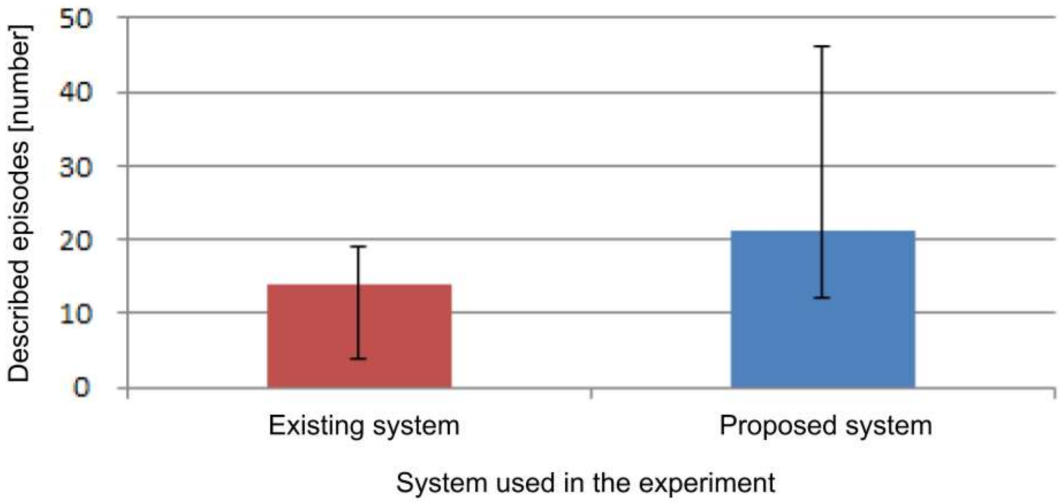

Figure 18. The average number of episodes described by users in Experiment 2-3.

Additionally, the content of the description was discussed. Using the proposed system, we found that there were several episodes about other experiences related to the designated event. For example, "There was a laboratory seminar on the day", "There was a schedule to make a research presentation in the near future", and "There was a work taking over the research was done at this time". Figure 19 shows the number of episodes of the experiences related to the designated event when using each system. The average when using the existing system was 4.33, and the average when using the proposed system was 8.50. The reason why the proposed system is greater is because the memory fragments are presented in association, so recalling becomes easier without conscious re-searching. From these results, we confirmed that detailed information including not only directly related information, but also indirectly related information can be recalled by using the proposed system.

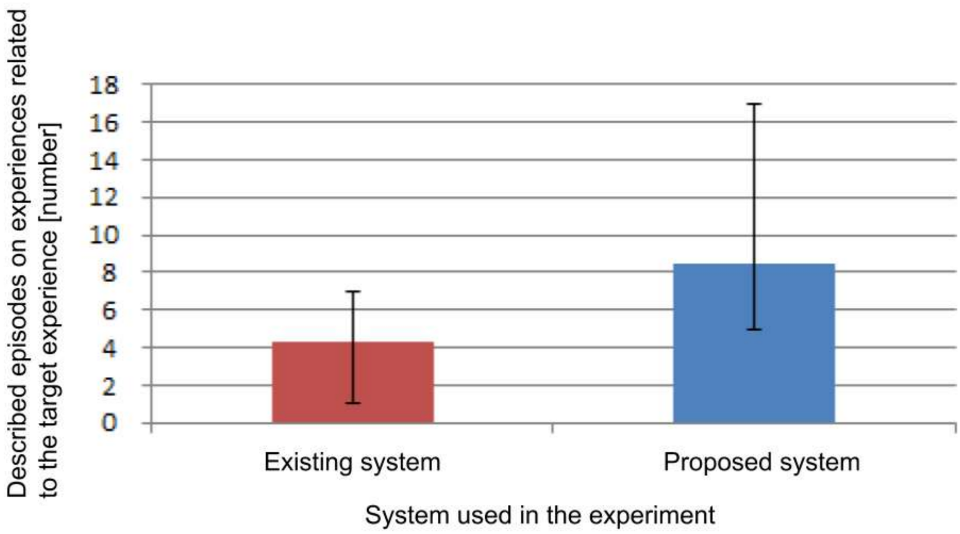

Figure 19. The average number of episodes including information on experiences related to the target experience in Experiment 2-3.

5.3.4. Questionnaires for Experiments 2-1, 2-2, and 3

After conducting Experiments 2-1, 2-2, and 2-3, we conducted questionnaires on the existing system and the proposed system for the users. In the questionnaire, we asked the following four points on memory recall using the existing system and proposed system.

- Q1: I was able to find necessary information quickly
- Q2: I am confident of the answers I recalled
- Q3: I was able to recall details about what was asked
- Q4: There are additional types of information that I could recall in relation to what was asked

The questions were answered in 5 levels (1 to 5). The meanings indicated by 1 to 5 are as follows.

- 1: No
- 2: Yes, but poorly
- 3: Yes, a little
- 4: Yes, good
- 5: Yes, very good

Additionally, we asked the users to freely describe how they felt using the system.

The results of these questionnaires are shown in Figure 20. For all questions, the value is higher when using the proposed system. In addition, when the t-test was performed at a significance level of 0.05, it was found that there was a significant difference in Q3 and Q4.

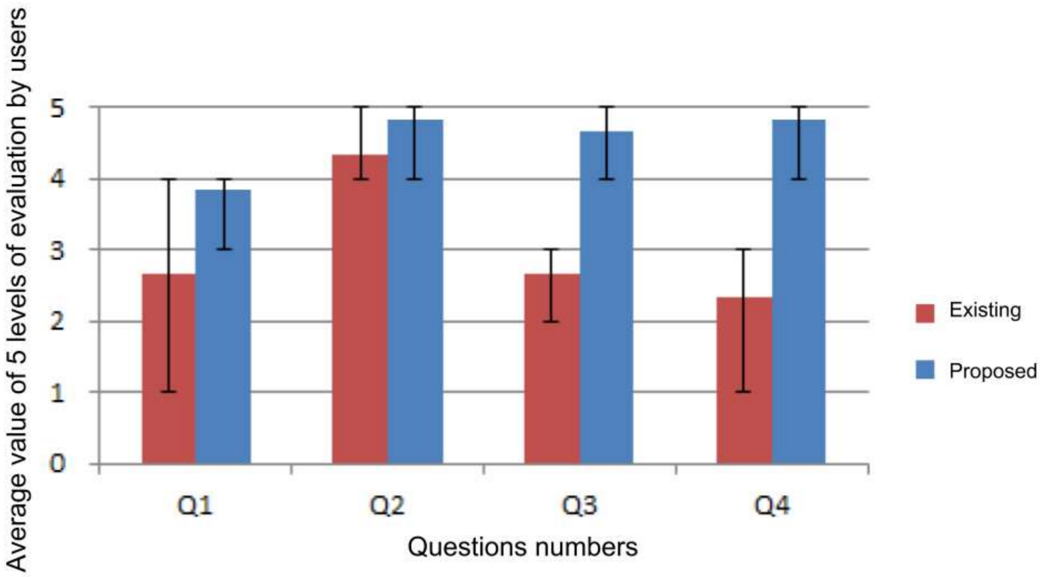

Figure 20. Average value of five levels of evaluation by users for all experiments.

We asked Q1 to see whether the user was able to recall quickly using the proposed system. As a result, the average when using the existing system was 2.67, and the average when using the proposed system was 3.83, and the opinions were that it was faster to recall when using the proposed system. These results also show that the time taken to recall in Experiments 2-1 and 2-2 was shorter using the proposed system.

We asked Q2 to see whether the users had feelings that they recalled correctly. As a result, the average when using the existing system was 4.33, and the average when using the proposed system was 4.83, both of which are high values. This is consistent with the fact that the correct answer rate in Experiments 2-1 and 2-2 was close to 100%. Although the difference was small, the proposed system had a higher value. Opinions were obtained in the free description part of the questionnaire. For example, there was an opinion that "It was good to be able to check across multiple information resources using the proposed system." Confirming multiple, varying kinds of memory fragments at the same time is considered to be one of the reasons why users felt confident with their answers.

We asked Q3 to see whether the user recalled several things about the experience by using the proposed system. As a result, the average when using the existing system was 2.67, and the average when using the proposed system was 4.67, and it was confirmed by t-test that there was a significant difference. This is supported by the fact that the number of episodes in Experiment 2-3 was greater when using the proposed system.

We asked Q4 in order to confirm whether the user could recall information indirectly related to the target experience using the proposed system. As a result, the average when using the existing system was 2.33, the average when using the proposed system was 4.83, and it was confirmed by t-test that there was a significant difference. This is supported by the fact that the number of episodes related to the target experience in the description of Experiment 2-3 was greater when using the proposed system.

Furthermore, we obtained opinions such as "I was able to recall the scene of the lab at that time in detail" and "I was able to recall even the smell and the cold feeling at that time" using the proposed system. It is considered that users have such an opinion because of the provision of associated memory fragments around the target memory fragment.

From the results of these questionnaires and their analysis, we confirmed the results that users can recall quickly and accurately using the proposed system. In addition, it was confirmed that details can be recalled as well as information related indirectly to the recalled target experience. In addition, it was confirmed that the user had the same tendency, as shown in the results of Experiments 2-1, 2-2, and 2-3.

5.3.5. Summary of Experiment and Evaluation

We conducted experiments to confirm the effect of each proposed function using the prototype system.

In Experiment 1, it was possible to acquire various memory fragments as AIRs from different services and applications; we confirmed that issue P1 was solved. We confirmed that problem P2 was solved because the imported memory fragments were related and autonomously composed the memory structure of the experience. In response to the user's request, since the proposed system presented effective memory fragments and their relationships, we confirmed that problem P3 was solved.

In Experiment 2, we confirmed that it was possible to support the memory recall accurately, quickly, and in detail; so we confirmed that effective memory recall support became possible using the system based on the proposals.

From these results, it was confirmed that each proposed function solved each problem, and collectively realized the effective recall support. As a result, the burden of work was reduced when supporting human activities using information obtained by information collection means such as a lifelog, which is the objective of this research.

In the evaluation carried out in this paper, we confirmed the feasibility of the system using big data. In this system, the time it takes for the memory fragment to be presented for the first time is about 1 s which can withstand practical use. However, a limitation of the system implemented in this paper is that memory fragments are presented one after another, and the time it takes to present all fragments is on the order of tens of seconds. Therefore, when the order of the number of AIRs reaches 1000 or more, it is possible that it takes much computation time or that display convenience is impaired. It is possible to deal with this problem by distributing the calculation cost by applying multi-agent hierarchy technology.

6. Conclusions

We proposed a memory recall support system based on the active acquisition and accumulation of memory fragments, and evaluated the usefulness of the system with experiments using the implemented system. We confirmed that it is possible to incorporate the lifelogs and electronic files, and present them according to the user's request. Additionally, through experiments with multiple users, we confirmed that the system is able to support effective memory recall.

Based on these results, we plan to introduce more diverse records and verify the effects of the proposed system. In order to realize a practical system using larger-scale data, we plan to introduce technologies related to the dispersion of the calculation cost.

Author Contributions: T.K. surveyed the core problems and conceived the concept of solution; K.T. designed and implemented the proposed system; K.T. and T.K. conceived and designed the experiments; K.T. performed the experiments; K.T., T.K. and T.K. analyzed the experimental results; K.T. wrote the paper. T.K. and T.K. provided various feedback and ideas to improve the paper.

Acknowledgments: This work was partially supported by a Grant-in-Aid for Scientific Research (C) No. 16K00292, from Japan Society for the Promotion of Science (JSPS).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Larry, R.S.; Eric, R.K. *Memory: From Mind to Molecules*; Roberts & Co.: Greenwood Village, CO, USA, 2008.
2. Tulving, E. Episodic and semantic Memory. In *Organization of Memory*; Academic Press: New York, NY, USA, 1972; pp. 381–403.
3. El Agroudy, P.; Machulla, T.; Rzayev, R.; Dingler, T.; Funk, M.; Schmidt, A.; Ward, G.; Clinch, S. Impact of reviewing lifelogging photos on recalling episodic memories. In Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct (UbiComp'16), Heidelberg, Germany, 12–16 September 2016; ACM: New York, NY, USA, 2016; pp. 1014–1019. [CrossRef]
4. Wang, W.; Subagdja, B.; Tan, A.H.; Starzyk, J.A. Neural Modeling of Episodic Memory: Encoding, Retrieval, and Forgetting. *IEEE Trans. Neural Netw. Learn. Syst.* **2012**, *23*, 1574–1586. [CrossRef] [PubMed]
5. Tilman, D.; El Agroudy, P.; Le Viet, H.; Schmidt, A.; Niforatos, E.; Bexheti, A.; Langheinrich, M. Multimedia Memory Cues for Augmenting Human Memory. *IEEE MultiMedia* **2016**, *23*, 4–11. [CrossRef]
6. Aizawa, K.; Tancharoen, D.; Kawasaki, S.; Yamasaki, T. Efficient retrieval of life log based on context and content. In Proceedings of the 1st ACM Workshop on Continuous Archival and Retrieval of Personal Experiences (CARPE'04), New York, NY, USA, 10–16 October 2004; ACM: New York, NY, USA, 2004; pp. 22–31. [CrossRef]
7. Memon, M.; Mahoto, N.; Khuhawar, F.; Tanaka, J. Retrieval of Life Logs based on Users Context. *Sindh Univ. Res. J. (Sci. Ser.)* **2015**, *47*, 851–860.
8. Harvey, M.; Langheinrich, M.; Ward, G. Remembering through lifelogging: A survey of human memory augmentation. *Pervasive Mob. Comput.* **2016**, *27*, 14–26. [CrossRef]
9. Lamming, M. Forget-me-not: Intimate computing in support of human memory. In Proceedings of the FRIEND21: International Symposium on Next Generation Human Interface, Meguro Gajoen, Japan, 2–4 February 1994.
10. Guo, B.; Zhang, D.; Yang, D.; Yu, Z.; Zhou, X. Enhancing Memory Recall via an Intelligent Social Contact Management System. *IEEE Trans. Hum. Mach. Syst.* **2014**, *44*, 78–91. [CrossRef]
11. Bahrainian, S.A.; Crestani, F. Cued Retrieval of Personal Memories of Social Interactions. In Proceedings of the First Workshop on Lifelogging Tools and Applications (LTA'16), Amsterdam, The Netherlands, 16 October 2016; ACM: New York, NY, USA, 2016; pp. 3–12. [CrossRef]
12. Zhou, L.; Cheng, Y.; Gurrin, C.; Qiu, Z. From Lifelog to Diary: A Timeline View for Memory Reminiscence. In Proceedings of the iHCI'13, Dundalk, Ireland, 12–13 June 2013.
13. Di, W.; Ah-Hwee, T. MyLife: An Online Personal Memory Album. In Proceedings of the IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT), Singapore, 6–9 December 2015; pp. 243–244.

14. Kubota, A.; Tominaga, T.; Hijikata, Y.; Sakata, N. Adding Search Queries to Picture Lifelogs for Memory Retrieval. In Proceedings of the IEEE/WIC/ACM International Conference on Web Intelligence, Omaha, NE, USA, 13–16 October 2016; pp. 689–694.
15. Kinoshita, T. A Method for Practical Use of Distributed Information Resource: Design of Active Information Resource. In *IEICE Technical Report, Artificial Intelligence and Knowledge-Based Processing*; IEICE: Tokyo, Japan, 1999; pp. 13–19. (In Japanese)
16. Baoning, L.; Kinoshita, T. Active Support for Using Academic Information Resource in Distributed Environment. *Int. J. Comput. Sci. Netw. Secur.* **2007**, *7*, 69–73.
17. Sugawara, K.; Hara, H.; Kinoshita, T.; Uchiya, T. Flexible Distributed Agent System programmed by a Rule-based Language. In Proceedings of the Sixth IASTED International Conference of Artificial Intelligence and Soft Computing, Banff, AB, Canada, 17–19 July 2002; pp. 7–12.
18. Uchiya, T.; Maemura, T.; Hara, H.; Sugawara, K.; Kinoshita, T. Interactive Design Method of Agent System for Symbiotic Computing. *Int. J. Cogn. Inform. Nat. Intell.* **2008**, *3*, 57–74. [CrossRef]
19. Google Calendar API. Available online: https://developers.google.com/google-apps/calendar/ (accessed on 28 February 2017).