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Model-based Reminiscence : Guiding Mental Time Travel by Cognitive Modeling

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ABSTRACT
This paper proposes an approach to elderly mental care called model-based reminiscence, which utilizes cognitive modeling to guide a user's mental time travel. In this approach, a personalized cognitive model is constructed by implementing a user's lifelog (a photo library) in the ACT-R cognitive architecture. The constructed model retrieves photos based on human memory characteristics such as learning, forgetting, inhibition, context, and noise. These memory characteristics are regulated with parameter values corresponding to cognitive and emotional health. The authors assumed that a user's mental health could be assessed from their reactions to photo sequences retrieved by models with various parameter settings. The authors also assumed that it would be possible to motivate a user by guiding their memory recall with photo sequences generated from a healthy optimal state model. As a preliminary step toward realizing model-based reminiscence, this paper presents a case study in which an elderly person was presented with photo sequences generated by a cognitive model having her lifelog. From the verbal protocols obtained in the case study, it is suggested that a model-based lifelog presentation elicits storytelling and social reactions, pointing to the feasibility of the proposed concept.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords
cognitive architecture; ACT-R; autobiographic memory

INTRODUCTION
A lifelog is a subjective experience recorded with various digital media. Although a lifelog can be created using many different types of media, this study focused on a visual lifelog, consisting of private photos, because it provides an effective means of evoking a specific past memory in a user [8]. Such lifelog technology is becoming increasingly common and plentiful in our society with convenient recording devices and large-sized storage [6]. To date, many researchers have used large lifelog technologies to support human cognitive functions such as memory recall [7].

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From the viewpoint of cognitive neuroscience and psychophysiology, remembering the past is essentially linked to the imagining of future activity [18]. Both cognitive functions are referred to as "mental time travel" because they direct a person's attention to events that have occurred/will occur in other than the present moment. Moreover, researchers have pointed out that such a state of consciousness relates to a brain network called the default mode network (DMN) [18], which includes a connection between the posterior cingulate cortex (PCC) and dorsal medial prefrontal cortex (dmPFC), and have defined regions that are activated in the resting state rather than goal-oriented tasks [12]. Importantly, DMN is said to change with age, and has attracted the attention of researchers who hope to employ it as a biomarkers for mental illnesses such as dementia [3] and depression [19].

Mental time travel to the past is also accompanied by a fresh emotional states. The relationship between memory and emotion has been the subject of studies for a very long time. In clinical situations, memory recall of a "personal golden age" is said to bring about psychological health and well-being [16]. A recent study also indicated that optogenetically activating positive memory engrams suppress depression-like behaviors in mice [13]. On the basis of these assumptions, activities such as life reviews and reminiscences are commonly conducted as a means of supporting the elderly.

Based on the above studies, the mental activities evoked by observing a lifelog can be summarized into the following three types: memory recall, future imagining, and emotional arousal. From these activities, we can consider the application of a lifelog to the care of the elderly. In this application, emotional and cognitive health are assessed from reactions to a presented lifelog, and can also be used to motivate future activity by effectively stimulating the user's future imaging.

Such an intelligent care system requires a mechanism for guiding a user's mental time travel in a desired direction. For this reason, we are proposing a concept of *model-based reminiscence*, where a system has two user models: a model concretizing the user's mental state, and a model representing a desired mental state of the user. The system uses the former to monitor the user's mental state, and the latter to guide the user's mental time travel.

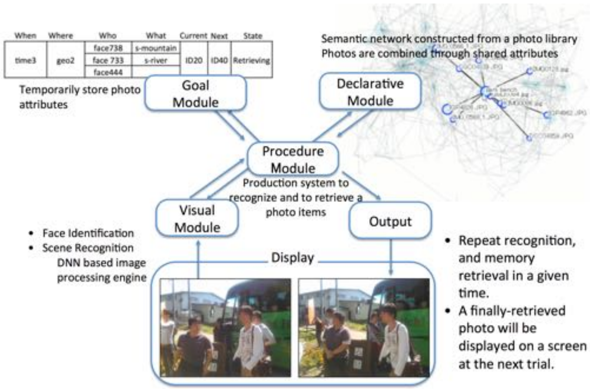

Figure 1. Overview of the model

Furthermore we believe that such a user modeling method can be realized by using a cognitive architecture, which has been developed in the field of traditional cognitive science. A cognitive architecture is a common platform used to construct a model for simulating human cognition. Researchers who use cognitive architecture usually call such simulation models *cognitive models* [1, 10]. Individual cognitive models can be developed by implementing domain-/user-specific knowledge and parameter values in a cognitive architecture. In other words, varieties of user models corresponding to individual user states can be developed with a combination of knowledge and parameter values [2]. From this viewpoint, a cognitive model of mental time travel can be developed by using user-specific memory, that is, a lifelog and user-specific parameter values estimated from the user's reactions to presented model behaviors.

We so far developed a prototype model for mental time travel using a cognitive architecture, and explored parameters that correspond to the mental states of the elderly through model simulations. Several user experiments in which the model behavior was presented to the user were conducted. In the next section, we briefly present an implementation of the prototype model, and then the third section presents a case study that explores a user's reactions to the model behavior. Last, we discuss the studies that we intend to pursue in the future to realize the concept of model-based reminiscence.

MODEL AND SIMULATION

ACT-R model

The cognitive architecture used in the study is ACT-R [1], which is a well maintained architecture used by many researchers. The ACT-R architecture has several modules corresponding to independent cognitive functions including procedure, declarative, visual, aural, manual, and goal modules. The behaviors of these modules have been tuned to fit the level of human performance obtained in previous psychological studies. Therefore, the use of this architecture provides some guarantee of cognitive plausibility for a constructed model.

Figure 1 shows the make-up of our model that uses the ACT-R modules. The main part of this model is a declarative module, which is constructed from a user's lifelog, while the other modules are used to simulate the process of human memory

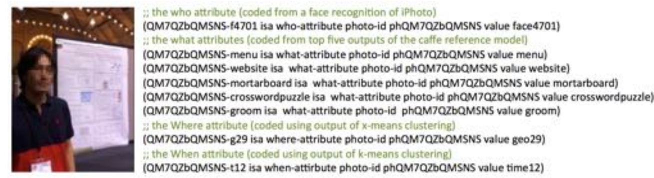

Figure 2. Examples of attribute coding

retrieval from the observations of a photo. This model uses photos stored in a personal photo library such as iPhoto of the Mac OSX to construct declarative memory. Especially, four types of attributes are extracted from each individual photo in a photo library, namely, the *when*, *where*, *who*, and *what* attributes. These attributes were determined in a study by Wagenaar [20]. For four years, he recorded his own experiences by using these attributes, and conducted a memory experiment on himself. Other researchers used these attributes to develop photo browsers [11].

In this study, the first two types of attributes are tagged as cluster ID obtained with k-means clustering to Exif metadata (date-time and geo-tag information)[1]. The who attribute is tagged by using face recognition of the photo library software. The what attributes are tagged with scene recognition using a deep convolutional neural network. We are currently using the caffe reference ImageNet model[2].

Examples of attribute coding are shown in Figure 2. In the ACT-R architecture, the lists presented in this figure are called "chunks." Each chunk has a unique chunk name in its first element (e.g., *QM7QZbQMSNS-f4701*). In this study, we named each chunk by combining the GUID value (e.g., *QM7QZbQMSNS1*), given by the iPhoto library, with an attribute value (e.g., *f4701*). The following elements of each chunk consist of slot name/slot value pairs. The *isa* slot discriminates the types of attributes. The *photo-id* and the *value* slots indicate the GUID of the photo and the attribute value, respectively.

A collection of such chunks can be regarded as being a network in which photos are connected with shared attributes. The model sequentially retrieves a photo by following a link within the network. In the implementation of ACT-R, this sequential search is made with a retrieval cue in the form of a production rule[3], which is constructed from the attributes recognized from the currently presented photo[4]. If several photos match a retrieval cue, the ACT-R select that photo with the highest *activation value* whose computation has been devised to reproduce the results of past psychological experiments. In

[1]Technically, the number of clusters for the where attribute was determined by x-means method. The k-means clsutring for the when attribute was conducted with the number of clusters determined by x-means for the where attribute to uniform resolutions of the two attributes.

[2] http://caffe.berkeleyvision.org

[3] The model has four retrieval rules corresponding to the four types of attributes. These rules are selected based on utilities values updated by given rewards. In the simulation presented in this paper, however the model didn't receive rewards, and randomly chose them.

[4]The recognized attributes are stored in the goal module.

our model, it is computed as a combination of the following effects.

- Forgetting: The model tends to retrieve photos taken recently. The old photos are not likely to be retrieved in a normal setting.
- Learning: The model tends to retrieve photos that have been frequently retrieved in the past. Even if a photo was taken in the distant past, it will be retrieved if it has been frequently retrieved in the past.
- Inhibition: The model can temporally inhibit the learning effect for a short time.
- Context: Although the model retrieves a photo based on a cue corresponding a single attribute, a photo that shares the greater number of attributes with the current photo is more likely to be retrieved.
- Noise: The above effects can be reduced by introducing a logistically distributed noise factor.

The strength of the above effects is controlled by parameter values, which might represent individual user states. The specific parameters and computations of the forgetting, learning, context, and noise can be found in [1], and the computation of the inhibition is presented in [9].

Simulation

Simulation settings

To demonstrate how the model can be applied to the care of the elderly, a simulation experiment was conducted. In this experiment, the personalized model of the first author was constructed by implementing the first author's lifelog in the ACT-R model described above. This model has 3,202 photos taken from 1977-2014. These photos were routinely managed by the first author's iPhoto library. Except for unknown bystanders, all the faces detected by the iPhoto face recognition function were named. Photos taken by digital cameras as well as scanned photos were included. For those photos without Exif metadata, the first author coded the locations and date-time information manually.

Among the five effects presented in the above, the presence of inhibition (with/without) and the degree of noise (high/low) were manipulated [5]. The parameter values concerning effects of the learning and the forgetting were fixed in the simulation [6] because these effects were treated as basic mechanisms in the ACT-R architecture. In fact, the component calculated by these effects is called *base-level activation* in the literature related to ACT-R [1]. The parameter values related to forgetting are calculated from the difference in the current model time (set to 00:00:00, January 1, 2015) and the date-time information of each photo. Regarding the parameter of the context effect, we conducted a simulation in the other study. In this paper, we do not report the results because they do not have a significant effect on the results presented in this paper [7].

We ran the simulation 20 times for each of the four-parameter conditions. In a single run, the model sequentially retrieved 200 photos.

Simulation results

Figure 3 presents the frequency distributions of the recalled photos for each parameter condition. The horizontal axis corresponds to the recalled photo IDs, which are arranged in descending order of frequency. The vertical axis indicates the frequencies of each rank, averaged across the 20 simulation runs.

From the figure, it can be seen that a few photos dominate the distributions, especially under those conditions with only forgetting and learning effects (the left-hand blue line). The inhibition effect slightly suppresses such repetitive recall, as shown in the difference in the blue lines between Figure 3a and 3b. A more salient effect can be observed when comparing two noise conditions. In both Figure 3a and 3b, the high-noise conditions (the black lines) recall more various photos than the low-noise condition (the blue lines).

Discussion

In a previous study, researchers pointed out that a free recall made by the normal ACT-R model lead "pathological behaviors such as out-of-control looping [9]." Our results also replicated such behavior. We believe that these behaviors are not necessarily negative for our purpose. Rather, these behavioral patterns of the normal ACT-R model can be used to model several types of mental disorders. For example, Schacter described a memory error called "persistence" which involved an unwanted and repeated recall caused by post-traumatic stress disorder [17]. Dementia patients also exhibit behavior similar to the normal ACT-R model. The symptoms of dementia involve repetition in conversation, where the same information is repeated over and over again. These mental disorders indicate the necessity for cognitive or emotional regulations in addition the base level activation computation, to achieve healthy memory recall. The two parameters manipulated in the simulation can be assumed to act as mechanisms that enable ACT-R healthy memory recall.

We assumed that the parameters of the inhibition and the noise represent cognitive and emotional states, respectively. Inhibition can be regarded as being a function of the prefrontal cortex, which controls mental time travel as driven by the default mode network [18]. On the other hand, the noise parameters seem to represents emotional factors. Previous studies of ACT-R discussed the connection between the noise parameters of ACT-R and stress level [15, 4]. Especially Dancy et al developed a cognitive model for subtraction task under stressed conditions by attaching a physiological module to ACT-R architecture. In thier model, the noise parameter of ACT-R is connected with physiological epinephrine release [4].

[5] In "the with inhibition condition", the parameter values controling inhibition was set to the default (inhibition-scale = 5, inhibition-decay = 1.0. The noise control parameter (ANS) was set to 0.1 in the low noise condition, and 0.5 in the high noise condition.

[6] The decay rate d = .5, the base-level offset $\beta = 15$

[7] In this paper, the MAS (Maximum Association Strength) parameter, indicating the strength of the context, is set to 10.

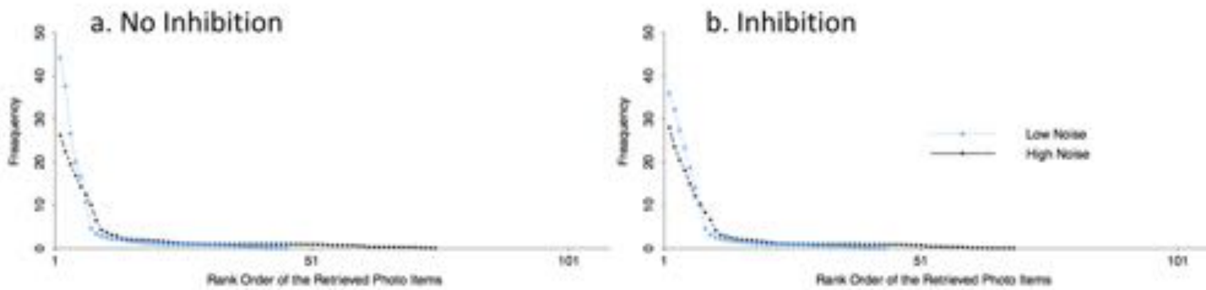

Figure 3. Freaquency distributions of retreived items

CASE STUDY

Assumptions

Based on the model presented above, a model-based photo slideshow can be developed. This slideshow system presents a user with photos retrieved by a model. The presented photo is periodically changed according to the content of the model's working memory (the goal module in ACT-R).

We assumeed that a model-based slideshow system can be used to monitor the mental states of a user. For example, if the user does not evoke a feeling of strangeness from the pathetic behavior discussed in Figure 3, this user possibly has some mental disorder. We also assume that the photo sequences generated by a certain specific model can motivate and inspire a user from the mental time travel theory.

As a preliminary step toward realizing such a model-based reminiscence, we have so far conducted exploratory experiments to connect user responses to a photo slideshow with various parameter settings. Although we have so far collected responses from more than twenty five participants, experimental conditions could not be systematically manipulated for these participants. Generally speaking, an experiment using lifelog media incurs a relatively high execution cost, and it is very difficult to control the participants' pre-existing knowledge, as would be attempted in a typical psychological experiment.

In our experiments, some participants were presented with slideshows developed from the model constructed from the first author's photo library, and some other participants were presented with slideshows developed with a photo book, which collected old Japanese scenes. However, these experiments did not success even as a partial evaluation of the model-based slideshow because it was hard for the participants to perceive the when, where, and who attributes from other people's photos. In fact, most of them could not distinguish photo sequences generated even from the model-based slideshow from randomly generated sequences.

Therefore, this paper reports on a single case where an older participant observed photo slideshows constructed from her own photo library, to qualitatively explore the utilities of the developed model-based slideshow system.

Method

Participant and materials

In this case study, a 75-yo Japanese woman was participated. Using the 603 photos she owned, a model of her memory was constructed. These photos were taken from 1942 to 2015. Most of them were originally taken with photographic films but they were scanned and tagged with date and geographic information using the notes written on her album. Before the experiment, she agreed to the use of her photos and the data produced by the study for academic purposes.

Procedure

In this study, the participant was presented with eleven sequences of photo slideshow, each lasting for five minutes. The five sequences were generated randomly (the random condition) while the other six were generated from the ACT-R model (the model-based condition). The sequences in the model-based condition were generated by two different parameter settings: that setting in which all the effects in the second section were included, and that with all the effects other than the forgetting effect. With the latter setting, the model could retrieve old photos. We included this setting because memory recall of a "personal golden age" is assumed to give rise to psychological health and well-being [16], as noted in the first section. However, we will not discuss the difference in the model-based condition, instead focusing on the difference between the model-based and random conditions.

The presentation order of the sequences was semi-randomized with the application of a constraint so that the same condition does not continue for more than three times. During the presentation of the photo sequence, the participant was required to verbalize her thoughts (the think-aloud method [5]). Following each presentation of the photo sequence, the participant was answered several questions.

Results

Due to the characteristics of the case study, this paper does not attempt to show any quantitative differences between the model-based and random conditions. Rather, we will show the qualitative characteristics of the user reactions under the two conditions. In the following part, we first present findings observed from specific sequences of both conditions, and then the overall tendencies of each condition are discussed based on excerpts from the verbalization.

Categories	*Excerpts*
Recognizing/ Remembering	Where did we go? I can see Mt. Fuji. **[where]** This photo was taken when I was a junior high school student. **[when]** Modern times. **[when]** She is Keiko-san.I couldn't return her kindness. **[who]** I can see snow. **[what]**
Emotion/ Motivation	I'm feeling nostalgic. **[emotion]** Adorable kid. **[emotion]** The happiest period of my life. **[emotion]** I will work hard again, getting back to my roots. **[motivation]** Seeing these photos makes me happy. I have done well so far. **[motivation]**
Evaluation	This photo was taken when we went to UNESCO village. I think the order of the photo is mixed up. **[the random condition]** It's perplexing. Interesting to observe this photo after seeing the old photo. It's changed. **[the random condition]** It seems that (the system) likes the photos too much. After that, I followed a different career than these girls. I'm getting a lump in my throat. **[the model-based condition]** What is the purpose of the presentation? Is there any meaning? I'm not connected to these people now. **[the model-based condition]** Again? I don't understand thoughts (of the system). What the meaning of this photo. This girl with the pig tails was a classmate. It seems to have something in the back of its mind, showing similar photos many times. **[the model-based condition]**

Table 1. Categories of the verbalization. Excerpts are translations from Japanese. The words in parentheses were not explicitly verbalized by the participant, but supplemented by the authors. The bold words in brackets are subcategories noted in the text.

Examples of the photo sequences and verbalization

Figure 4 shows examples of the photo sequences under the model-based (no forgetting effect) and random conditions. For each condition, this figure presents the first ten photos that the participant observed to indicate a naive response to the slideshow. The figure also includes verbalized comments for each presented photo.

From the figure, we can see the difference in the coherence between the two photo sequences; in the model-based condition, the presented photos seem to share the same attributes, such as dates and scenes, while the photos in the random condition do not seem to share such attributes.

More interestingly, such coherence of the photo sequence was reflected in the contents of the verbalization. The verbal sequence in the model-based condition contains words appearing in different photos, such as "school trip (first and the second photo)", "Junior high school (first, third, sixth photos)" and "Nakamura-sensei (eighth and ninth photos)." From these common words, the verbalizations elicited from the model-based slideshow appear to be connected with each other.

Categories of the verbalization

Table 1 summarizes the verbalizations obtained in this case study, dividing into three categories. This analysis does not intend to claim that all the verbalization obtained in the study can be fit into these categories. Rather, we tried to support our assumptions based on these excerpts from each category.

The first category in the table is related to activities recognizing the presented photos or remembering the past memories. Importantly some verbalizations in this categories can be tagged as who, what, where, and when. As noted in the previous section, the ACT-R model retrieves a photo that shares these attributes with the current photo. Therefore, those verbalizations give some psychological validity to the model process.

The second category is related to emotion and motivation. As mentioned in the first section, the observing of a lifelog sometimes evokes fresh memories accompanied with strong emotional states. To support this assumption, we observed many emotional verbalizations as shown in the first three excerpts of this category. From the fourth and the fifth excerpts, we also confirmed that the observing of a lifelog evokes motivation for future activities based on the mental time travel theory. To sum up, these suggest utility of model-based reminiscence as tool for the elderly care.

The above two categories were observed regardless of the conditions. Contrary to these categories, the verbalizations in the third category, which evaluate the presented photo sequences, were found to be qualitatively different between the two conditions. In the random condition, the participant used words such as "mixed up," "perplexing," and "changed." On the other hand, in the model-based condition, the participant said, "It seems that (the system) likes the photos too much," "What is the purpose of the presentation," and "have something in the back of its mind." These verbalizations inquire about the intentions of the presented photos and, interestingly, words usually applied to humans, not artifacts, are used (e.g., "thoughts," "likes," and "mind").

Before this case study, the participant did not have knowledge about cognitive modeling, and were not instructed that there were several types of slideshows. Considering these conditions, it can be considered that this participant produced spontaneous social reactions to the model-based slideshow. Furthermore combining the result obtained in Figure 4, such social reaction entails storytelling, combining verbalizations. This characteristic of the reaction to the model-based slideshow seems to be important for the sustainability of human-agent interactions [14]. Therefore the presented case study is useful for indicating the proof of concept and the feasibility of the model-based reminiscence.

CONCLUSION

In this paper, we presented a concept of the model-based reminiscence, and prototyped a cognitive model of mental time travel. The constructed prototype model was applied to both a simulation study and a case study in which an elderly person participated. We assumed that the presented simulations successfully demonstrated the applicability of the model to the model-based reminiscence though the originality of the simulation result was limited. Moreover, the case study indicated characteristics of the model-based slideshow system for a user, indicating the feasibility of the proposed concept.

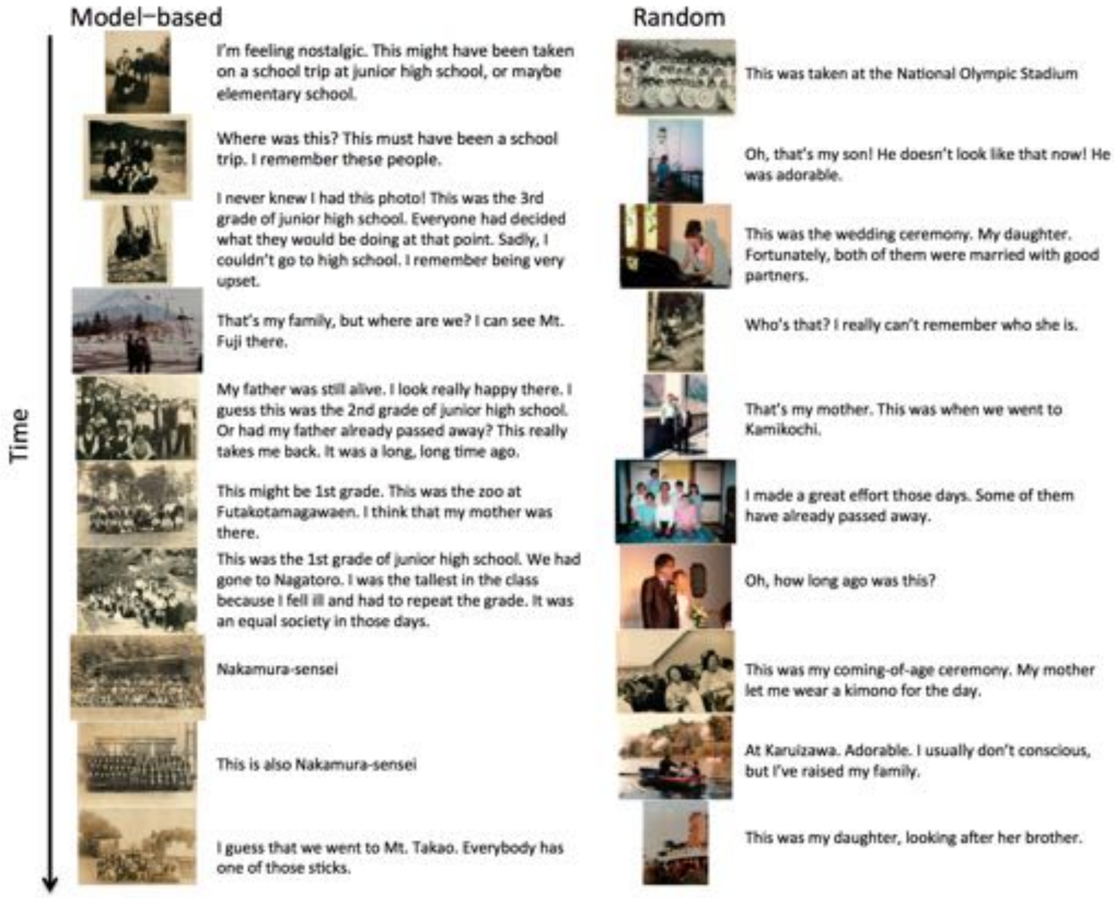

Figure 4. Example photo sequences in the model-based and random conditions. The part of the figures are masked for privacy protection.

However, there are many restrictions on the studies described in this paper. Because of the difficulty related to the use of lifelog, controlled experiments have not yet been conducted. Those tendencies presented in the previous section should be quantitatively confirmed. There are many parameters that should be manipulated in user studies. To overcome such limitations, we are now planning to conduct experiments, in which the lifelogging phase is included in the experimental procedure.

Our future studies will also address the development of an interactive model-based slideshow system, which modulates the model parameters from the user's reactions. We have especially examined the possibility of using bio-signals such as the heart rate or brain waves. As noted earlier, the ACT-R noise parameter is assumed to correspond to physiological epinephrine release, which is regulated by the automatic nervous system. Therefore it might be possible to modulate this parameter by directly inputting known bio-signals corresponding to stress such as the low-/high-frequency heart rate ratio or the alpha wave of EEG (electroencephalogram). It may also be possible to reward a model by using bio-signals for pleasantness [21] to modulate the utility values for photo retrieval rules. We believe that realizing these interfaces would provide an effective means of guiding a user's mental time travel, naturally estimating parameters concerning cognitive and emotional healthiness.

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