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Automatically assisting human memory: A SenseCam browser

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SenseCams have many potential applications as tools for lifelogging, including the possibility of use as a memory rehabilitation tool. Given that a SenseCam can log hundreds of thousands of images per year, it is critical that these be presented to the viewer in a manner that supports the aims of memory rehabilitation. In this article we report a software browser constructed with the aim of using the characteristics of memory to organise SenseCam images into a form that makes the wealth of information stored on SenseCam more accessible. To enable a large amount of visual information to be easily and quickly assimilated by a user, we apply a series of automatic content analysis techniques to structure the images into "events", suggest their relative importance, and select representative images for each. This minimises effort when browsing and searching. We provide anecdotes on use of such a system and emphasise the need for SenseCam images to be meaningfully sorted using such a browser.

Keywords: SenseCam; Lifelogging.

. . . If we remembered everything, we should on most occasions be as ill off as if we remembered nothing. It would take as long for us to recall a space of time as it took the original time to elapse, and we should never get ahead with our thinking . . .

(James, 1890)

The SenseCam, developed by Microsoft Research in Cambridge, UK, is a wearable camera worn via a lanyard around one's neck (Hodges et al., 2006). On average this device captures an image every 22 seconds, and temperature, accelerometer (read motion), light, and passive infrared readings on average every 1.5 seconds. This device provides individuals with a visual record of their day, which may provide powerful autobiographical retrieval cues (Berry et al., 2009).

Work from our laboratories suggests that between 2000 and 5000 SenseCam images can be generated in the typical day. As an example of the large amount of data generated by the "lifelogging" that SenseCam facilitates, one person who wears the device on a daily basis has produced approximately 3,125,000 images in the last 38 months. For the SenseCam to be a useful rehabilitation tool in memory-impaired groups in any ongoing sense, we believe it is important to

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http://www.psypress.com/memory http://dx.doi.org/10.1080/09658211.2010.509732

facilitate researchers, caregivers, and participants in finding the images they wish to identify in this vast collection of images. One strategy to achieve this has been to suggest to caregivers that participants only use the device for significant events, thus reducing the total amount of images to sift through. In short, the instruction is to wear the device only for periods that the caregiver anticipates will be memorable (e.g., Berry et al., 2009). This, too, has been the most pragmatic means of assessing the quality of the device: where people are tested on their memory for particular events (Berry et al., 2007)

We feel it is more desirable to use the SenseCam in a way in which one does not have to predict the later memorability of a prospective event, nor risk missing important and novel occurrences by using it selectively. By crude analogy with the human system, it seems desirable to ensure that material is encoded continuously, but that retrieval is selective and organised. That is, all SenseCam images should be available, but not necessarily accessible (Tulving & Pearlstone, 1966). In this paper we present a technological solution for dealing with the large amount of information generated by SenseCam.

Earlier visualisation methods for reviewing SenseCam images include a clustered time view of query results (Gemmell, Bell, Lueder, Drucker, & Wong, 2002) and a geographical map with the wearer's route highlighted and images popping up along the route (although this requires the user to carry a GPS[1] data-logging device in addition to the SenseCam), and an interactive story-authoring interface that results in a slide show (Gemmell, Aris, & Lueder, 2005). The dominant presentation paradigm for these methods is a conventional "replay" or fast-forwarding of the images sequentially, more formally known as rapid serial visual presentation (RSVP) (Spence, 2002). This method provides the reviewer of images with a sense of what happened during the day as if looking at a movie of the day from the user's own perspective; but given the large number of images taken, fast-forwarding at 10 images per second would still take 5 minutes to review just 1 day.[2] Fast-forwarding of temporally ordered images of a day's events can be an engaging experience, but at the same time it causes problems of cognitive overload as trying to absorb a fast sequence for over 5 minutes can be tiresome, especially in someone with cognitive impairment. A momentary distraction could miss an important image, and even with a pace controller such as pause/rewind, intense concentration is required for the duration of the reviewing. In addition, transitions from one event to another or from one location to another are difficult to notice without a more distinctive indication of where the event boundaries are.

The problem of sequential playback or fast-forward is also found in playing video sequences and has been the driving factor for many video browsing tools that have been developed (Smeaton, 2004), most notably the extraction of thumbnail-size keyframes for spatial browsing which removes some usability problems with the sequential fast-forwarding/fast-rewinding method. In this article we outline two implemented applications that leverage an automated structuring process to turn the linear and sequential nature of the original SenseCam image set (incorporating various sensor values too) into an interactive, spatially oriented (image-driven) experience in which the user can more easily review days' worth of images likely requiring a lower cognitive load (Sweller, Van Merrienboer, & Paas, 1998).

In this paper we describe computing systems that we built to automatically structure and organise SenseCam data and later facilitate quick retrieval of desired events with a lower cognitive load on the user, through returning them fewer candidate events that are more relevant to the information they seek. We believe that research into understanding how the human mind works is useful in guiding the development of these automated computing systems. The main considerations are: (1) as the human mind thinks in terms of events, SenseCam data should be stored as event; (2) as distinct events are encoded more strongly, we automatically attempt to identify those events; (3) as the human mind works by association, similar SenseCam events to a given event should be easy to find.

METHOD

In this section we first discuss how the above goals are realised. Second we describe two implemented systems to gain feedback on the usefulness of our automated techniques. Finally in

[1] GPS (global positioning system) is a mechanism to automatically locate a person's location anywhere on earth.

[2] One week would take 35 minutes to review, with 1 year taking over 30 hours to look back on using RSVP alone!

this section we detail a group of participants who provided us with feedback on using the systems we built.

Automatic structuring and interactive retrieval of SenseCam images

> *. . . Digital memories surpass biological memories by enabling people to directly see and interact with captured information. This powerful capability can help people manage their personal information . . .*
>
> (Barreau et al., 2007)

We have developed a suite of functions applied to SenseCam data that automatically provide digital memory retrieval cues. We structure our processing into a number of logical steps that exploit various characteristics of human memory (See Figure 1).

Event segmentation

Memory perspective. Human memory segments a *continuously experienced present* into a series of discrete events (Williams, Conway, & Baddeley, 2008). Zacks and colleagues elaborate on this, stating that "*. . . segmenting ongoing activity into distinct events is important for later memory of those activities . . .*" (Zacks, Speer, Vettel, & Jacoby, 2006, p. 466).

Computing solution. We segment sequences of images into distinct events, such as having breakfast, working on a computer, etc. This is achieved very quickly using the SenseCam's on-board motion sensors to recognise changes in activity (see Doherty & Smeaton, 2008a, for further detail). This event segmentation process typically results in a day's images yielding 20–30 events, and presenting these units of information significantly reduces the potential information overload associated with presenting so many images.

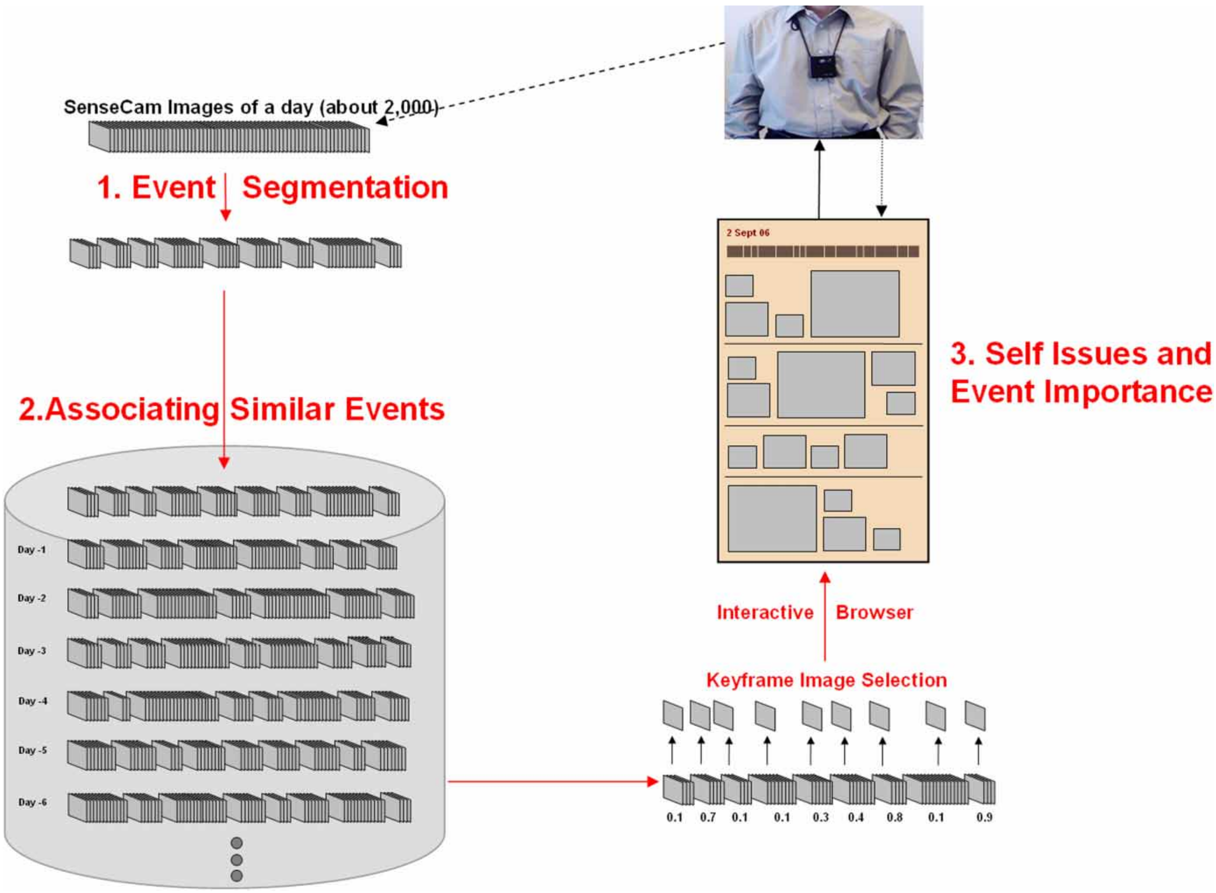

Figure 1. Our model of automatically structuring SenseCam images. To view this figure in colour, please see the online issue of the journal.

The most representative image in an event is also determined, which aids the visual browser aesthetics by summarising the event in just one image.[3] Similar to keyframe selection in a video sequences, the image that best represents the set of images in an event is selected as the representative image of that event (see ‘‘Keyframe Image Selection’’ in Figure 1). We select the highest-quality image near the midpoint of the event (Doherty, Byrne, Smeaton, Jones, & Hughes, 2008).[4]

Associating similar events

Memory perspective. Human memories are stored within a conceptual framework, which means that related events and locations are associated in memory (e.g., Conway, 2005).

Computing solution. We provide users with automated search functions to find events similar to a given event, e.g., ‘‘show me other times when I was at the park’’. By intelligently representing events through the fusion of MPEG-7 image descriptions and the on-board sensor values, we found that users can find events related to any given ‘‘query event’’, with three out of the top five returned results generally being relevant. The technical description is not repeated here (but see Doherty, O'Conaire, Blighe, Smeaton, & O'Connor, 2008, for detailed information).

Self issues and event importance

Memory perspective. Memory is organised by self-relevant structures and goals (e.g., Conway, 2005). Considering that more-distinctive events are better remembered (Brewer, 1988), it follows that we should suggest events to a user in a cued manner that may be more interesting. This notion of distinctiveness is very important, and we believe that those events that are most interesting for users to review from their own lives are the events that were most distinct to them, e.g., talking to a new person, going to a new place, etc.

Computing solution. It is computationally difficult to automatically gauge personal significance of images stored in a visual lifelog. This is due to the well-known computational problem of the ‘‘semantic gap’’, where computers fail to translate bytes into real semantic meaning (Smeulders, Worring, Santini, Gupta, & Jain, 2000). We believe an effective approach is to combine the automated detection of faces (to indicate social engagement) with detecting how visually novel each event is. To obtain the novelty score, each event in a day is visually compared, using MPEG-7 colour and edge descriptors, to see how dissimilar it is to every other event occurring at the same time of day within the previous fortnight (Doherty & Smeaton, 2008b).

Implementation of SenseCam browser

Due to development time constraints in implementing image analysis extraction features that could be distributed to and easily used by participants, we developed two distinct systems. One was an event-based browser that we distributed to international research groups, and another incorporates all facets of our visual lifelog processing cycle.

Event-based browser. This browser first automatically segments sequences of collected images into distinct events or activities, based on the sensor values alone. These events are then visualised as displayed in Figure 2. The top left corner of the screen is a daily calendar, which allows a user to browse to a desired day. The currently selected day in the calendar is highlighted by a different background colour (the 19th of October 2006 in Figure 2). The middle column of the browser displays a single keyframe image of every event present in the selected day. The middle image in each event is selected as the keyframe image, meaning that processing is very quick. The events for the morning, afternoon, and evening have different background colours, to allow the user to navigate to the section of the day in question that they are most interested in reviewing. Events that are selected to be browsed in detail are highlighted with a red border and arrow as illustrated with the first ‘‘Afternoon’’ event in Figure 2. The right-hand side of the browser then displays all the individual images present in a selected event. Above the event's images, other details are given about the event, e.g., the start/end times, the duration of the event, and also any associated comments. Users can add

[3] Users still have access to all the images in the given event. For display purposes a single keyframe image is displayed to the user to summarise all the (broadly similar) images in the given event.

[4] In the cited work the keyframe was based on the most visually representative event image. A worthwhile future investigation would see if this technique selects the most powerful memory trigger too.

Figure 2. A cropped screenshot of the "event-based" browser.

textual comments to an event. Finally, if the user is interested in any particular image within the event they can click on it to display it in full size.

Advanced browser. Figure 3 provides an overview of the more advanced browser that was used by members of our research team. The top left region of the browser provides the user with calendar functionality where the user can select any desired day to show. Again, as with the event-based browser, this exploits the fact that people can estimate or infer the approximate time that events take place (Dumais et al., 2003). Days available for selection are highlighted in bright white text, with the current day on view highlighted via yellow font. The predominant focus of the browser is on the middle of the screen where numerous images of the day are displayed. These images were segmented into distinct events/activities, and on the browser each image is an event keyframe image, i.e., the image with the highest quality score. As can be seen, some images are larger than others, and those images that are larger correspond to events with a high importance score, suggesting more interesting events to review, which parallels the finding that distinct

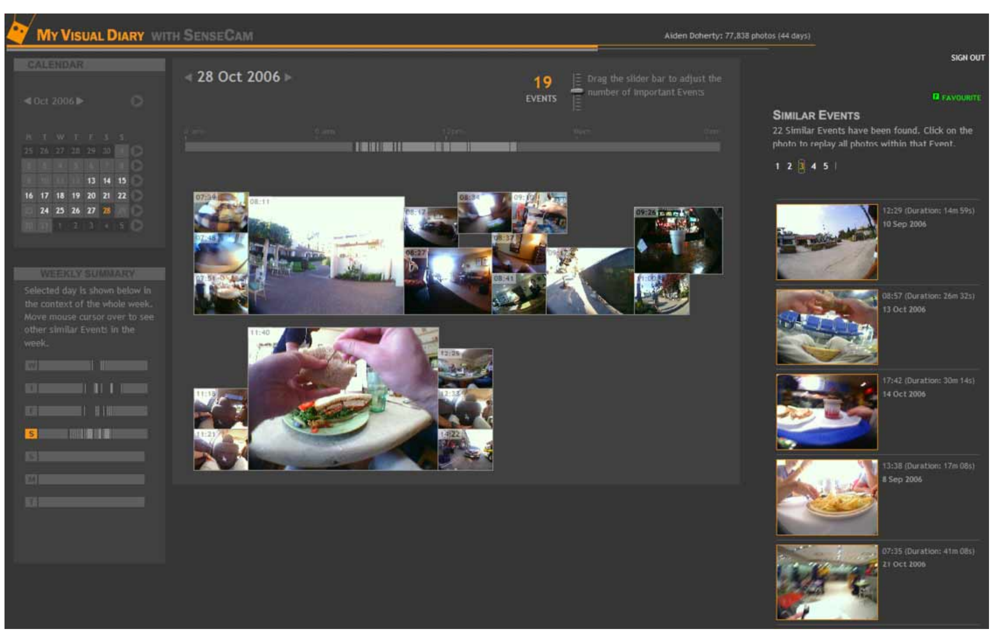

Figure 3. Our "advanced" browser; with event segmentation/interestingness/searching. To view this figure in colour, please see the online issue of the journal.

events tend to be better recalled. In the top left corner of each image its starting time is displayed. The information at the top centre of the browser details the day being displayed and also the number of events being displayed. The slider bar can adjust the number of events being displayed, and in the case of Figure 3 the 19 most important events, as determined by the system, are displayed to the user. Below the slider bar there is a timeline visualising when events started, and also their duration. The panel to the left of the browser titled ''Weekly Summary'', just below the calendar section, provides a timeline of other events in the days surrounding the day being displayed. Only those events that are similar to any of the events in the displayed day are visualised in the weekly timeline, taking advantage of the fact that the human mind stores items associatively and thus is curious to see other related events. When the user puts the mouse cursor over any event in the centre of the screen, the images are displayed at full size and played back at a rate of ten frames per second. The playback is stopped when the user exits the mouse cursor from the event. The other events are still visible and transparent in the background. The event is also highlighted in red in the daily timeline above, and the weekly timeline to the left too. Any events that are similar are highlighted in amber on the daily and weekly timelines.

Thus far we have displayed aspects of the application that highlight the usefulness of event segmentation in terms of detecting the different events, of automated event importance calculations to emphasise more interesting events, and of selecting a good keyframe for visual display. However, there are other capabilities that are useful to provide to the user. We provide the user with a menu of options anytime that they click on any event being displayed. This then empowers the user with much extra functionality. The user can add/amend a textual comment to any event via selecting an ''Add Caption'' option on the menu. The user can also add an event to their list of favourite events via selecting an ''Add To Fave'' option on the menu. Events can also be removed from the favourite list too.

The user is also provided with the important capability of searching for other potentially relevant events in their lifelog to a given event, by selecting a ''Find Similar'' option on the menu. A list of other potentially relevant events to the event in question are displayed on the ''Similar Events'' panel to the right-hand side of the browser, as illustrated in Figure 2, where keyframe images from the list of potentially relevant events to a given event are displayed. Other information regarding the date, time, and duration of the potentially relevant events is displayed too. The top of the panel also gives the user feedback on how many potentially relevant results were returned (22 in the case of Figure 3). As the event playback rate is at ten frames per second, it is excellent at giving the user the gist of what an event is about. However, if the user is interested in viewing a certain image in any given event, we provide the opportunity to view such images in a new tab of the browser. This new tab is opened when the user selects an ''Event Images'' option from the floating event menu bar. Once the tab is open, the user is presented with thumbnails of all the images in a given event, and they can then select any image to view it in full size.

Evaluation of the browsers

Participants. We presented nine participants, who wore SenseCams for varying periods over a 2-year period (May 2006 to August 2008), with one of the two different systems to review their own data (see Table 1). The ''event-based browser'' was distributed to five people in four collaborating SenseCam universities: the University of Tampere, Finland; Duke University, USA; University of Toronto, Canada; and Utrecht University, in the Netherlands. The ''advanced browser'' was used by four participants among our own research team.

The event-based browser was used in Utrecht by a participant who collected 102,113 images over a period of 55 days, which were segmented into 1290 events. It was also used in Tampere where one participant reviewed images received from six molecular medical workers, which amounted to approximately 72,000 images over a period of 52 days that were segmented into approximately 800 events (Byrne et al., 2008; Kumpulainen et al., 2009). At the University of Toronto two people have used this browser, one collecting 5524 SenseCam images over a period of 5 days, which were segmented into approximately 67 events. The other participant collected a much larger dataset. One person in Duke University has used this browser too and our evaluation section will focus on how useful our event-based browser was for these participants.

TABLE 1
Overview of participants using systems implementing our lifelog browsing model

Participant	*Place* $^{(M/F,\ age)}$	*Browser*	*Number of days*	*Number of images*	*Number of events*
1	Dublin$^{(M,\ 35)}$	Advanced	614	1,686,424	19,995
2[a]	Dublin$^{(M,\ 24)}$	Advanced	60	92,837	1182
3	Dublin$^{(M,\ 35)}$	Advanced	21	44,173	443
4	Dublin$^{(M,\ 28)}$	Advanced	23	40,715	505
5	Utrecht$^{(M,\ 35)}$	Event-Based	55	102,113	1290
6	Tampere$^{(F,\ 30)}$	Event-Based	52	~72,000	~800
7	Toronto$^{(M,\ 28)}$	Event-Based	5	5524	~67
8	Toronto$^{(M,\ 28)}$	Event-Based	Unavailable	Unavailable	Unavailable
9	Duke$^{(F,\ 26)}$	Event-Based	Unavailable	Unavailable	Unavailable
TOTAL	*9 users*		*830 days*	*1,971,786 images*	*23,415 events*

[a]It should be noted that participant 2 is one of the authors of this article.

The advanced browser was used by four participants at Dublin City University. They used the system to review their own SenseCam images to view past days/events. In total the participants collected 1,864,149 images over a period of 23 months, which were segmented into 22,125 events (Table 1). We realise that Participant 1 may appear to skew the dataset but we include him for two reasons: (1) to illustrate the volumes of data that can be gathered by enthusiastic lifeloggers; and (2) to provide an accurate reflection on the effectiveness of the model in dealing with scaled-up datasets.

RESULTS

Anecdotes received from participants

This section focuses on how effectively participants' images were segmented into distinct events/activities, how effective the event importance determination was, the usefulness of the selected keyframe, and the relevance of other retrieved events to a queried event. As the "event-based" browser was used in a number of remote locations, feedback on the event segmentation aspect of our model was elicited via an e-mail questionnaire. Feedback obtained via our four participants using the "advanced browser" was obtained in a one-on-one session monitoring their usage of the system on a particular day and prompting them for feedback on various aspects of the system. Note that this was work carried out within a computer science paradigm, with the goal of evaluating the device more generally, but we believe that they illustrate the benefit of the system more generally.

Event segmentation: Used by 9 participants (5 × event browser, 4 × advanced browser). Participants found the "event-based" browser to be very easy to use, given that it segmented images into events, and had no additional functionality that might have introduced an element of confusion. Our participant in Utrecht, commented:

> *... initially I was not sure if a pure time-based segmentation would have been sufficient already (e.g., new segment every 30 min). However, after using it, I think the one provided by your system is much better ... In Cape Town, I made a tour to the Cape of Good Hope. When browsing the pictures, I was interested in finding the ones that actually show the Cape. I remembered which day it was and given the segmentation, it was easy to find the related segments ...*

One of the Toronto participants commented:

> *... the calendar feature allows for easy recall of the events experienced in different days and gives an overall theme for each day. On certain events, I felt like the computer actually understood the photos and their sequence, segmenting them into appropriate events with sharp boundaries separating them ...*

Our participant in Duke University noted that the segmentation process sometimes wrongly "*... created several 'events' while that person was driving in her car ...*".

While pointing out some examples where the events were over-segmented, in general the researchers in Utrecht, Toronto, and Duke Universities found our process of segmenting images into events to be effective. While participants of our in-house "advanced browser" were able to identify certain instances where the segmentation algorithm incorrectly identified event boundaries, the event segmentation was recognised as an important and useful facet.

Our participant in Tampere was not so concerned about extra events being incorrectly proposed by the system; however she did want to make sure that all semantic boundaries were detected, to find out about every small event/activity in which the medical researchers were involved. To accommodate the wishes of this participant, we were simply able to lower a thresholding parameter so as to present more segmented events.

Participants made very few remarks on the keyframe selection choice in the advanced system. When prompted for a comment, participants made very general comments such as the keyframes selected are "*good*". In fact, when participant 3 was asked to make a more detailed comment, he responded:

> *... the performance overall is good, when I see each keyframe I know what the event is about, however given the fact that they're my events I have a good knowledge what the event is about regardless of the image given ...*

Participants did not seem very enthusiastic or appreciative about this aspect of the system, only commenting on the few cases where it incorrectly selected a representative keyframe image. This perhaps suggests that this is a less-striking feature for potential users of a SenseCam browser.

Associating similar events: Used by 4 participants (4 × advanced browser). All participants found the retrieval facility very useful in the "advanced browser". Participant 2 noted that "... *sifting through the query results I am reminded of many other interesting events and days that I want to review ...*"

Participant 4 also found the retrieval facet of the system "*very useful*". While this feature is useful, all participants also highlighted the need for better accuracy. This mirrors the findings of previous experiments where we found that the retrieval performance of some topics was excellent, but for other topics the performance was not (Doherty, O'Conaire, et al., 2008). Participant 3 was satisfied with his results for a query of walking in the centre of the city he was living in, commenting that "... *the first rank was wrong, but all the other results returned on the first page were relevant and also interesting ...*"

Participant 4 commented that "... *when trying to find other presentations I gave, I could only find one other relevant event. The search facility is useful, but needs better accuracy ...*"

Participant 1 had a desire to search for events by time and location, in a fashion quite similar to that carried out in the domain of organising traditional photographs (O'Hare et al., 2007). These features were not integrated into the application presented to the participants in this study, but could be integrated into future lifelogging systems. However, this participant was satisfied with the actual results returned for each query he requested, as the results were amusing and set the participant off on different browsing trails, which he enjoyed very much.

Self issues and event importance: Used by 4 participants (4 × advanced browser). Overall, participants found that emphasising more important/interesting events was very helpful. Participant 2 noted that "... *I like events being highlighted as they gave me a focus or trail to start browsing with ...*"

Participant 4 noted that he was "... *happy that the mundane events of working on my computer are either very small or hidden. I find the top two most important events proposed by the system pleasurable to review, and all the other events aren't interesting to look at, so the system is correct ...*"

However, participant 3 felt there was little benefit to the event importance, as he commented on being unable to trust the system to consistently identify the most important events; but against this he still felt it is a useful feature and noted that "... *I like the fact that events I manually marked as 'favourites' are then highlighted as important events ...*"

While all participants were agreed on the usefulness of highlighting important events, given these comments by participant 3 it is evident that not everyone was completely satisfied with the actual performance of the algorithm. Interestingly participant 1 noted that, while the most important events presented by the system were "*quite good*", some of his events of social interaction recurred quite regularly, e.g., having coffee with a work colleague. Participant 1 felt that these events, even though they contain a high element of social interaction, should not be weighted as strongly due to the fact that they are not highly novel.

Figure 4. Our open-source released browser. To view this figure in colour, please see the online issue of the journal.

DISCUSSION

Until recently lifelogging was still a new area with no commercial devices or tools to support people to start recording their lives, yet the SenseCam device allowed us to explore issues related to this emerging field. We experienced and discovered several issues with constant visual recording and subsequent access to one's lifelog. However, we believe the tools we are developing to provide effective retrieval mechanisms, based on neuropsychological principles, are moving in the right direction. The model we have built is particularly timely given the commercial release of SenseCams in the form of the Vicon Revue.[5]

In this article we have shown that various aspects of our computational model (i.e., event segmentation, associating similar events, and self issues and event importance) were all anecdotally found to be helpful. It remains to be seen whether memory-impaired groups will likewise benefit from this tool for accessing SenseCam images, and we believe this is a worthwhile future area of collaborative investigations.

While event retrieval is a very useful function, we feel that in future it will be interesting to provide ‘‘free text’’ or multi-faceted retrieval functionality, where people can easily search not only via ‘‘query-by-example’’ but also for events in a certain location, or for events of a certain temperature condition, or for events taken on a certain day of the week, etc. It would be a worthwhile future area of research to work with many participants to determine how this functionality should be most effectively offered. Most notably, if memory rehabilitation is to be furthered through devices such as SenseCam, it seems that browsers such as those described here are critical, and also the collaboration of computer scientists and neuropsychologists. Indeed our model can be further improved by incorporating the idea that retrieval is another form of encoding, and this may help in determining those events that score highly in the ‘‘self issues and event importance’’ facet of our model.

Since carrying out the study detailed in this article, our ‘‘event-based’’ browser has been used to manage 40 users' data by 19 institutions across eight countries, from backgrounds including: computing science, information science, epidemiology and public health promotion, neuropsychology, clinical practices, etc. An updated and easier-to-use version of our ‘‘event-based’’ browser (see Figure 4) has been released on the codeplex website.[6] This is an open-source release, meaning that the software is free to be used by anyone, and also meaning that it can be modified and extended by interested parties. Already in the first 4 months there have been

[5] http://www.omg3d.com/html/IPLicenseagreement.html

[6] http://sensecambrowser.codeplex.com/

over 200 downloads of this software, which we will continue to improve and update.

In summary, the SenseCam has displayed much potential as a device that may help improve the quality of life of those with memory impairments. Much research up to now has been carried out on selected events, as memory researchers have been overwhelmed by the sheer volume of SenseCam images produced. However, to build up a more complete picture of people's lives, to make better informed decisions, and to have the chance to capture those unexpected moments, we strongly believe that individuals should be encouraged to wear their SenseCams as much as possible. This will require an effort on the part of information researchers to manage this large amount of visual SenseCam images. We have released a SenseCam browser and our research efforts are ongoing to build more intelligent and easy-to-use systems, which will be of benefit to the numerous communities who now are building on the lifelogging platform.

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