DELIVERABLE 3.2
Initial design and implementation of the memory visualization and narrative generation

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Short description

Deliverable 3.2 documents the first design and implementation of visualization of a part of a robotic companion's memory. This feature is a specific module as part of the long-term memory system under development in WP3. Memory visualization of the robotic companion (Care-O-bot® 3) aims to support the user in remembering past events from the human-robot interaction history, including those that the user found 'memorable' (e.g. interesting or unclear/problematic) and to explore the robot's view during past human-robot interactions - which may help the user to better understand the robot's behaviour. Potentially, this ability to explore interaction histories could enable third parties (e.g. robot technicians, carers, family and friends) to monitor, maintain and improve the robot's abilities and services. This work is related to a diverse set of disciplines including cognitive psychology, human-robot interaction, database management and information retrieval. The technological implementation of memory visualization is straightforward since the goal was to provide a feature that is operational by the end of the first project year (completion of task T3.3).

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1 Introduction

In Deliverable 3.1 we illustrated our general motivations and related research, which led to the discussion of some existing human-robot interaction (HRI) issues which can be addressed by the visualization of a robotic companion's memory, visualization of the robot's view, the understanding of a user's daily routine and the creation of augmented episodic memory to help users in remembering past events. Here we illustrate an implementation using the Care-O-bot® 3 (COB3) robot.

Research in memory visualization for HRI is also supported by the following issues. First, the pace of improvements in various robotic technologies means that long-term interactions between robots and people in naturalistic environments has become feasible. Second, sensory technologies are advanced and digital storage is cheap and plentiful, thus it is possible to record our daily activities in a life-log system. The purpose of this deliverable is to explain the concept of memory visualization and its challenges. Here we set the stage for the discussion by reporting on common problems caused by memory loss in elderly people and introducing the initial implementation framework with the use of the COB3. Finally, we conclude the deliverable with some future work and provide possible directions that this research can lead to.

To focus on the proposed features of memory visualization, we will demonstrate the details of how the robot records events through executing actions based on sensory information, contexts of a situation or user input. Following that we will provide a discussion of the possible advantages provided by memory visualization and benefits of, and challenges faced, in the current implementation in the COB3.

2 Related research

In this section we start by reviewing common issues experienced, especially by the elderly, resulting from memory impairment, and the cognitive training that is available. Following that we consider the research field of Personal Information Management and life-logging, hinting at how HRI can bring a new dimension into this area. In addition to the literatures reviewed in D3.1, these considerations allow us to envision the potential of the current research in robot memory visualization. Finally, at the end of this section we describe the research work that resulted from the LIREC [1] FP7 EU project in memory visualization which has provided a basis and justification for the initial implementation described in this report.

[1] Living with Robots and Interactive Companions (LIREC). http://lirec.org

2.1 Ageing population and memory loss

According to the Office of National Statistics, by 2031, the over 80's population in the UK is predicted to double to 5 million [3]. This extension in life expectancy has been linked to improved quality of life and advances in medical technology. However, even in the 'healthy' ageing population neurological changes are commonly observed, and often associated with gradual degenerative alteration in brain function, which is accelerated for those persons suffering Alzheimer's and Parkinson's diseases. According to the Alzheimer Europe July-August Newsletter [4], age remains the single most important risk factor for dementia. The number of people who require long-term care is rapidly increasing and the UK government intends to deal with this need by encouraging the elderly to stay at home and receive care from relatives - a cheaper alternative to full-time care home staff [3]. Contact with family and friends/neighbours has a vital role in the well-being of elderly people, in terms of the social and emotional contact and support they provide, but increasingly, their role as a care-giver is asked for. However, as the number of older people increases, the relative proportion of younger people available to provide such support decreases.

One of the common cognitive impairments associated with normal ageing (and brain damage) is memory loss, which is also one of the most frequent complaints of the elderly and clearly one that negatively influences the quality of life. More precisely, dementia is defined as memory impairment (amnesia) plus one or more of the following symptoms for a period of at least 6 months before diagnosis: difficulty with language, problems with complex movements, difficulty with identifying objects and impaired executive functioning – making everyday decision- making difficult [5]. Alzheimer's disease (AD) is the most common cause of dementia. It is a decline in memory and cognitive ability which is of a sufficient degree to impair functioning in daily living. So far, only a few approaches have been formulated to tackle this problem, mainly through techniques called cognitive rehabilitation and cognitive training (see an overview in [6] and [7]).

To help AD patients, psychiatrists in the last decade have developed various cognitive training methods to cognitive functioning as alternatives or supplementary treatments to pharmacological interventions (see a comprehensive overview in [8]), Cognitive training strategies include two main approaches: compensatory and restorative. For example, for an AD patient who has difficulties in remembering what to buy in a shopping trip to a supermarket, a *compensatory* approach to this problem may involve e.g. writing a detailed shopping list which clearly shows every item to buy; in contrast, a *restorative* approach may involve the patient repeatedly questioning him/herself about the items' name. So far both approaches are very much reliant on patients motivating themselves. However, increasingly research project are investigating the use of robot technology to provide cognitive assistance and reminders.

The goal of the ACCOMPANY project in general is to enable elderly people to age in their own homes with the help of robotic companions. There are currently various projects with related objectives on the way [19,20] and an overview of the state of the art will be given in the next paragraph. Addressing the problem of the demographic change in western societies

[17] becomes increasingly pressing since the maintenance of life quality for the aging population is desirable. The independence and satisfaction of the living of elderly people is threatened by the physical and cognitive changes they are facing [10]. A conceptual model for the description of successful aging was developed by Baltes and Baltes [18]. They categorise in their selection, optimisation and compensation model (SOC) goals and challenges elderly people are confronted with in everyday life. For the work on memory visualization within the ACCOMPANY project specifically the problems related to the compensation of the loss of memory capabilities are relevant. These mnemonic strategies, specifically in the "mind and technology" approach [18], include memory aids [21]. When integrating these memory aids in robotic home companions, the challenge is how to provide the best and most comfortable support for the elderly user.

Research on reminders drawing on contextual information, has been conducted on handheld devices such as PDAs and Mobile Phones [22]. In HRI a lot of work on the ability to remind users of activities to be performed (prospective) or prior events (retrospective) has been done. Autominder was an initial attempt to make reminders more intelligent and dynamic, and was implemented on the Nursebot embodiment [23]. Intelligence and dynamics was also one of the aspects of the system proposed by the Robocare project [24].

More recently, work has been carried out focusing on persuasive technology. The work done as part of the EU FP7 project KSERA [25,26] for example, focuses on both the ability of the robot to draw on information not readily available to the user and its ability to persuade, in order to safeguard the health of the user. Other examples for assistance and reminders for elderly people with dementia through multimodal interactions and smarthouse integration are the EU FP7 CompanionAble project [27] and the MOBISERV project, which incorporates information from wearable technologies to further contextualise such reminders [28].The project Florence [29] introduces a commercially available robot as an autonomous lifestyle device for ambient assisted living, providing multiple services to users, including an Agenda Reminder service application that allows the elderly to share information with carers etc. At present, little information is available on the exact functionality, implementation and user testing results of the reminder functions used in the above mentioned projects. Future comparisons of those results with the results we will obtain in ACCOMPANY will help identifying strengths and weaknesses of different approaches.

2.2 Personal Information Management

The main research goals in Personal Information Management (PIM) are to investigate how people perform information acquisition, organisation, maintenance, retrieval and use [1]. An emphasis is here on information that is relevant and meaningful to the specific user. In recent decades personal computers, handheld devices and mobile phones have generated excitement due to the potential enhancement of the human ability to process and manage information. Researchers in PIM define that personal information combines to form a single personal space of information (PSI) for each individual [1]. It means information items that are experienced directly by a person are usually under the person's control, but might be seen as a vast sea of personal information. Therefore a person's sense of control over information is crucial to fulfil various roles in the person's life.

In addition to programs providing basic support for the management of appointments, to-do lists and contact information, we believe research in robotic companionship can bring a new dimension to PIM, given the fact that a robot shares living space and works together with its user(s) for an extended period of time. Here the autonomy of the robot plays an important role in capturing the user's everyday activities as it neither requires user involvement for the recording and storing process, nor requires the user to wear a device to capture information (which may be considered as redundant and sometimes intrusive). Furthermore, events stored in the robot's memory, or a structured log file with activity details as shown in this deliverable, allow tagging to be carried out automatically [2] and thus ease the searching of a particular piece of information for retrieval.

The approach presented in this deliverable, as a first step towards memory visualization for the COB3 robot, creates a memory of interaction histories/sequences of events that allow users to tag/label events that were meaningful for the user, e.g. interesting, or problematic events. A comprehensive investigation of PIM issues as applied to robot companions would go beyond the scope fo the project. However, results from the evaluation of this feature in user studies, as planned in ACCOMPANY, may provide insights into how the memory visualization feature could be developed in future to manage personal and meaningful information for a user in an efficient and acceptable manner.

2.3 Autobiographic memory and life-logging

Human memory is a highly dynamic system that makes available certain memories of events based on a hierarchy of information and the contexts of a memory retrieval situation. Arguably human's episodic memory is driven by personal significance – only events which tend to be relevant to the achievement of important goals are remembered [9]. Such important events in our lives construct the identity and self-image of a person [12]. Therefore remembering these events is crucial to us. In contrast, life-logging is the process of automatically and continuously recording various aspects of one's life in digital form without loss of information. Researchers developed a computer-based solution to assist people in reviewing their visual life-logs and showed that the deficit of human memory can be addressed using such solutions [10,11]. The idea was to invite users to wear a GPS-enabled camera device in their everyday life. Following that a computer program collects the information from the camera and then segments visual life-logs into events, allowing event similarity and event importance to be computed [11].

For one of the typical experimental settings of life-logging users needed to wear a camera device for a very long period of time (e.g. multiple years in [11]) in order to collect enough information for the purpose of analysis. This required a large computer storage space, routine data back-up processes, as well as strong data mining algorithms to find out most relevant materials from the data collected to give best accessibility to the user – satisfying the need of personal recollection. Our research in ACCOMPANY faces a similar challenge as life-logging approaches, namely how *meaningful* will users find a large amount of human-robot interaction histories, and how they would be able to retrieve and make sense of the information.

2.4 Related Research - Memory Visualization in the LIREC project

In this section we report on previous research in the area of memory visualization, findings that have been exploited in the current project.

An HRI project LIREC (EU Framework Programme (FP7/2007-2013) under grant agreement n° 215554, March 2008-August 2012) investigated the visualization of a robotic companion's long-term episodic memory. A smaller sized mechanoid (mechanically-looking) robot called 'Sunflower' was used in the project. Sunflower's interaction history was stored in, and retrieved from, the robot's Episodic Memory, and visualization of user past experiences could be achieved through an embedded touch interface to the robot.

2.4.1 Pictures captured in the visualised memory

Pictures of the environment were captured in a particular moment during the robot's goal execution, and then the storage address of the picture was linked to its Episodic Memory in a chronological sequence. Figure 2.4.1 shows an example of memory visualization with the interaction picture sequence taken by the Sunflower robot.

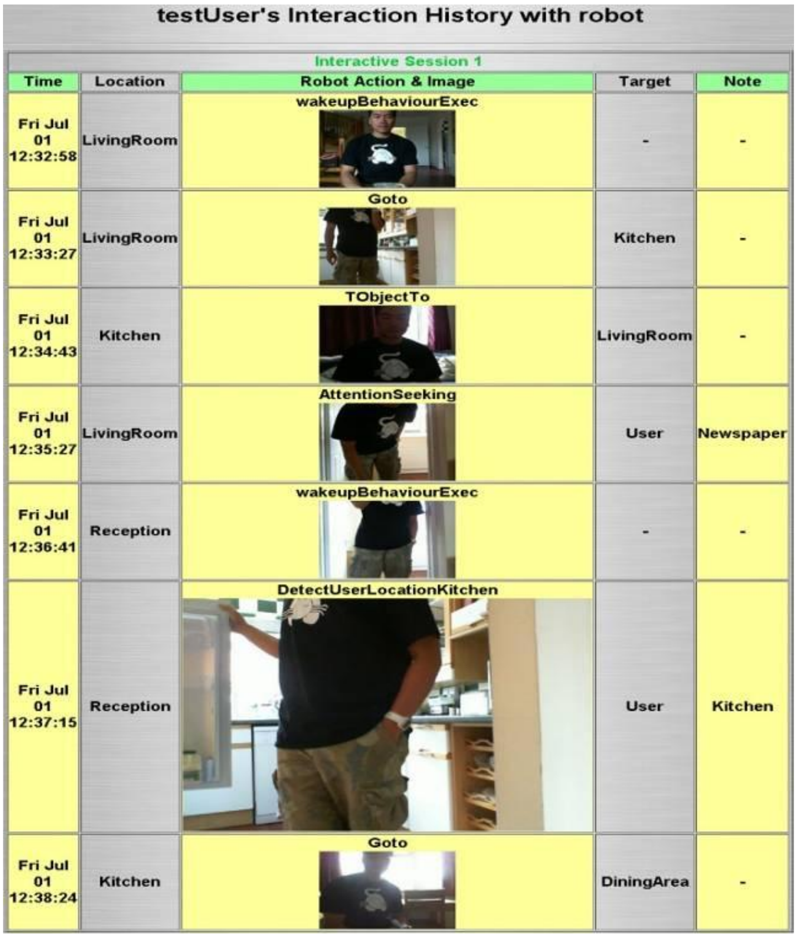

Figure 2.4.1. **Visualization interface in LIREC**. This shows the chronological sequence of events remembered by the Sunflower robot .

Upon an execution of a goal in Sunflower, the robot camera competency (called by the Person Detection module) is attached to the action to achieve the goal. This picture-taking competency could be attached at any point of an action execution i.e. at the beginning, end, or middle of the competency list dedicated for an action. Note that there was no sensory activation information provided in the visualized memory of Sunflower in the LIREC project, and due to the design of Sunflower, no object manipulation was available.

2.4.2 Robot House 2011 long-term experiment and results

A preliminary long-term experiment[2] to study the effect of memory visualization integrated in the LIREC architecture in a human-robot interaction context was carried out in the summer of 2011. 12 participants (4 males and 8 females, between 18 and 65 years old) with different backgrounds (including students, housewives, and retired elderly people) spent approximately an hour per week for 12 weeks to interact with autonomous robots in the Robot House. Each week they experienced a complete interaction session, called a *miniature day* that contained a mixture of short scenarios.

Participants felt comfortable in interacting with the robot and took the initiative of issuing commands through the graphic user interface of the robot. The robot's Semantic Memory was utilised to retrieve participant's preferences for their daily activities in the robot house and Episodic Memory was used to create interaction histories for the purposes of event visualization [13].

Results from the experiment included initial feedback from participants through the use of questionnaires, and their answers to an open question at the end with regards to the robot's usefulness. The participants responded to a series of items intended to gauge the usefulness of the event visualization feature, which formed a unidimensional scale (8 items, Cronbach's α =.86) with possible scores ranging from 1 (Most negative) to 5 (Most Positive). The mean score was 3.96 (SE .17), suggesting an overall positive sentiment to this feature. Participant responses to the open-ended question are shown in Table 1. Participant 12 did not respond. Note that the last participant (P11) raised the issue of increased storage space due to the memory.

Table 1 Open-ended responses to Memory Visualization feature

Participant	**Parts of answer and highlighted key words (*italic texts*)**
P1	"Sometimes it's *good to remind my daily routine* or to do things automatically…"
P2	"It will *act as a perfect reminder* just in case I was rushing and forgot to carry out some tasks."
P3	"... (sometimes) my *short term memory can be poor*"
P4	"It would help me *organise myself*"
P5	"Could help by reminding me of *routine a sort of animated calendar*."

[2] Reported in Deliverable 5.5 "Integration and Tests", FP7 LIREC (Living with Robots and interactive Companions), grant agreement no 215554, Ed. Ana Paiva, 2012.

P6	"So it would be easier to *remember what exactly I need to do during the day*."
P7	"Gives me *more time to remember things*."
P8	"Helpful to *use it like a diary* or help remember things I need to do."
P9	"*Help me remember*. It could *predict what I wanted more*."
P10	"The *robots could be your notebook* at home, you won't need to write your meetings in a paper, you could put your meetings in the robot."
P11	"Why: *help to remember*. Why not: Sometimes maybe *lost a lot volume of disk* when record everything."

Based on the positive feedback of users towards memory visualization in the LIREC project, we revisited and significantly improved the design for the ACCOMPANY project.

3 System Design and Implementation

In this section we give an overview of the *initial* design and current implementation of our memory system in the COB3. We will then discuss how this memory system is used by the 'action sequences' and how the sensors both in the UH robot house and on the COB3 are connected to the system. We will further explore the users' interface to the memory system and how they can use it to explore the robot's action memory.

3.1 COB3 modules

The COB3 system provides a number of modules that can be accessed in order to provide detailed information regarding the state of the robot, as well as providing the ability to issue mid level commands for the robot to execute. Examples of these commands are 'move the base to the kitchen' and 'raise the tray'. For commands involving movement, the COB3 is capable of performing the low level calculations required to reach the desired location. When moving the base, the COB3 develops a navigation plan to follow, then constantly monitors for obstacles and updates the plan accordingly. For movement of components, the COB3 determines a movement path that avoids collisions with other components on the robot. These features are encompassed in a module referred to as the 'COB Script Server'. The COB3 system itself is built as an extension to the Robot Operating System (ROS, [30]). ROS provides a unified method of communicating between systems located on different physical computers using different software. This messaging system is utilised to retrieve any required low level information about the robots state. Of particular importance is the angle of the COB3 camera, as this determines if the returned image is upside down.

The raw data from the COB3 is collected and processed, with the resulting values stored in a relational database for access by the remainder of the system. The COB Scheduler (a component developed as part of Work Package 3 which acts as a behavioural arbitration and execution mechanism) uses this data from the robot as well as the sensor data from the robot house in order to execute sets of stored robot competencies, called here either sequences (where sets of robots actions are carried out) or behaviours (where rules are associated with these action sequences).

3.2 Integration of sensors and action sequences

As the environment within the robot house changes, the values recorded by the sensors are stored within a relational database. These values are read by the COB Scheduler to determine which sequence (or robot behaviour) needs to be started. These sequences can be simple timed events, or far more complex scenarios involving the use of multiple sensors as well as the users' location or robot's location. Note that such sequences or behaviours are generated using the COB Sequencer component (developed as part of WP 3) which allows the matching of behavioural rules with robot actions. During the execution of a sequence, it is possible that one of several execution branches may be taken. This would be determined by the current state of the COB3 and house sensory state. Additionally, if a sequence/behaviour is currently executing and a higher priority sequence has its activation conditions met, the COB Scheduler is capable of halting the current sequence and starting the higher priority task. It is also possible for the sequence to add additional records during its execution. This would, for example, allow the user to understand why the COB3 chose to not perform part of a sequence or to take one sequence path over another.

3.3 Data structure and visualization interface

At this stage, the structure of the action history data is relatively simple. It will be extended during the remaining two years of the project. We exceed the developments carried out in the LIREC project above in a number of ways:

- The memory visualization is fully integrated into the complete sensory and action architecture (see figure 3.3.1) rather than being a separate instance
- The environmental sensory state becomes part of the visualization history
- The visualization can be generated both on behavioural execution, any sub-component of behavioural execution or on a timed basis
- The visualization system will be exploited in the remaining part of the project to provide further help in the co-learning and re-ablement functions
- Memory visualization will be integrated into the user preferences mechanism to allow users to choose when and where to perform it and who has access to the data.
- Users can tag/label 'memorable events', i.e. important as well as unclear/problematic events which can then later be shown selectively.

When an action sequence (that part of the behaviour which executes on the robot) is executed, a record is added to the history log table with the behaviour name, the location of the robot, and the current timestamp. This initial data is recorded separately to ensure that a record of the event is entered, and done in a timely fashion. Collecting of other relevant data is then started, which can take several seconds to complete. Currently, this additional data always consists of an image from the onboard camera, and a snapshot of the state of the robot house's sensor network.

When the user opens the visualization interface for this data, the system retrieves a list of all actions that have been recorded (see figure 3.4.2). This list is ordered chronologically, with the oldest actions appearing first. When a user selects an action, they are presented with the information that was recorded with that action. Currently, for all actions this consists of the image from the COB3 camera, and the sensor data (see figure 3.4.3). The data for the sensor network is presented twice, first as an image with icons to represent the on/off state of each sensor, followed by the raw sensor data that was stored. This allows the user to get a general idea of what the robot could 'see' when it began the action, whilst still providing a more technical user the data they would require to fine tune activation conditions for an action (see figure 3.4.4). A 'technical user' could not only be a technician or roboticist who intends to further develop the robot's behaviour, potentially it could, with the appropriate interface provided, include secondary users (such as carers, medical staff, family members) who may want to fine-tune the robot's behaviour, as well as primary users who have a technical interest and would be comfortable to re-programme the robot[3]. While investigating the issue of different user groups taking advantage of the memory visualization module goes beyond the scope of ACCOMPANY, it could be a fruitful avenue for future research.

The camera image and the sensor image are both initially presented as a thumbnail, but can be clicked to enlarge them to fill the current screen (see figure 3.4.5). This visualization interface is similar to the one that we have previously used in the LIREC project, and that served its purpose well. For ACCOMPANY, we have expanded this to include information about the robot environment as well as the robot.

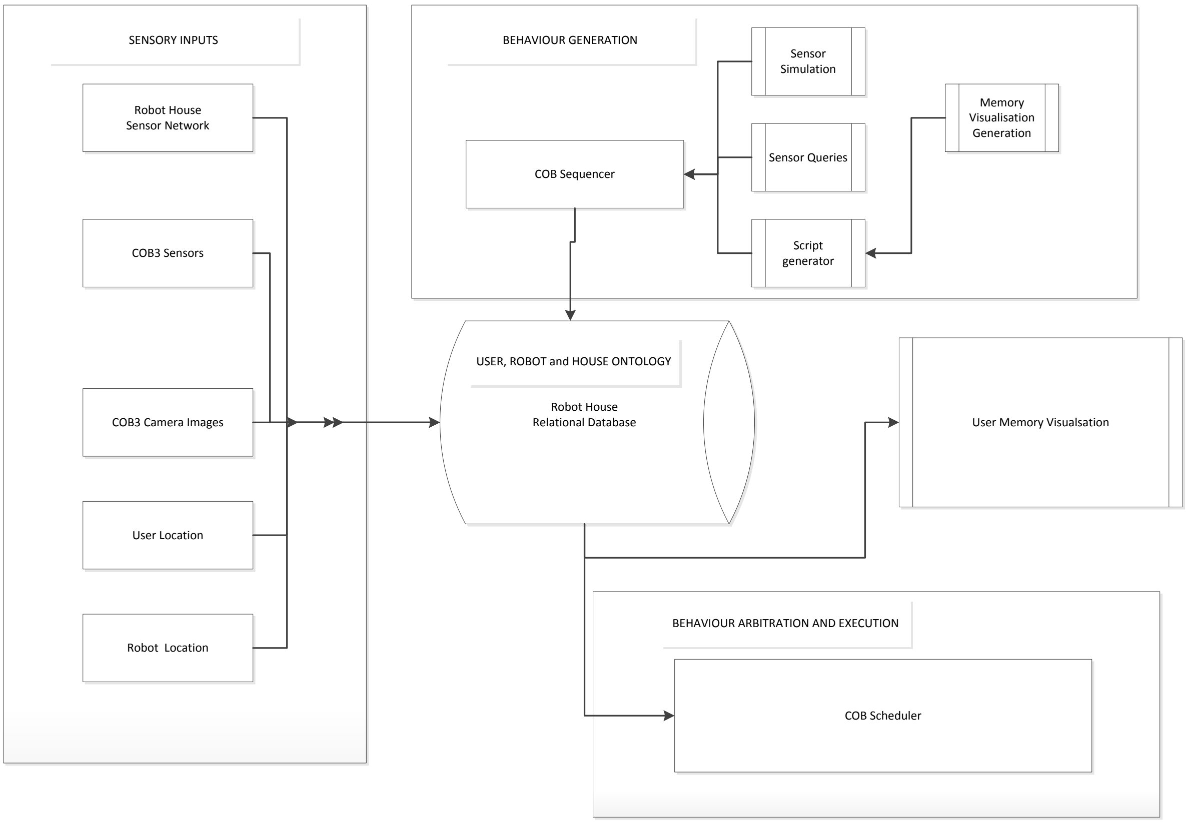

Figure 3.3.1. Relationship of Memory Visualization of Overall Memory Architecture. Central to the COB3 architecture is a relational database containing tables reflecting the ontology and relationships of the house sensor, the robot, objects and users. This data is updated in real-time from the house sensor network, the robot and the user location sensors. A behaviour generation module (COB Sequencer) allows behavioural rules and robot actions to be combined. Within this combination options exists for integrating memory visualization into the behavioural component. The components are scheduled and arbitrated via the COB scheduler, which if required generates the appropriate behaviours including memory

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[3] Note, the possibility of allowing the user to re-programme the robot would entail a number of safety and ethical issues, that would have to be addressed in future research in this direction.

visualization. The captured visualization can be viewed and searched via the User memory visualization component.

3.4 Examples of Current User Interface

Shown below are examples of the memory visualization user interface and how the interface relates to the central database ontology.

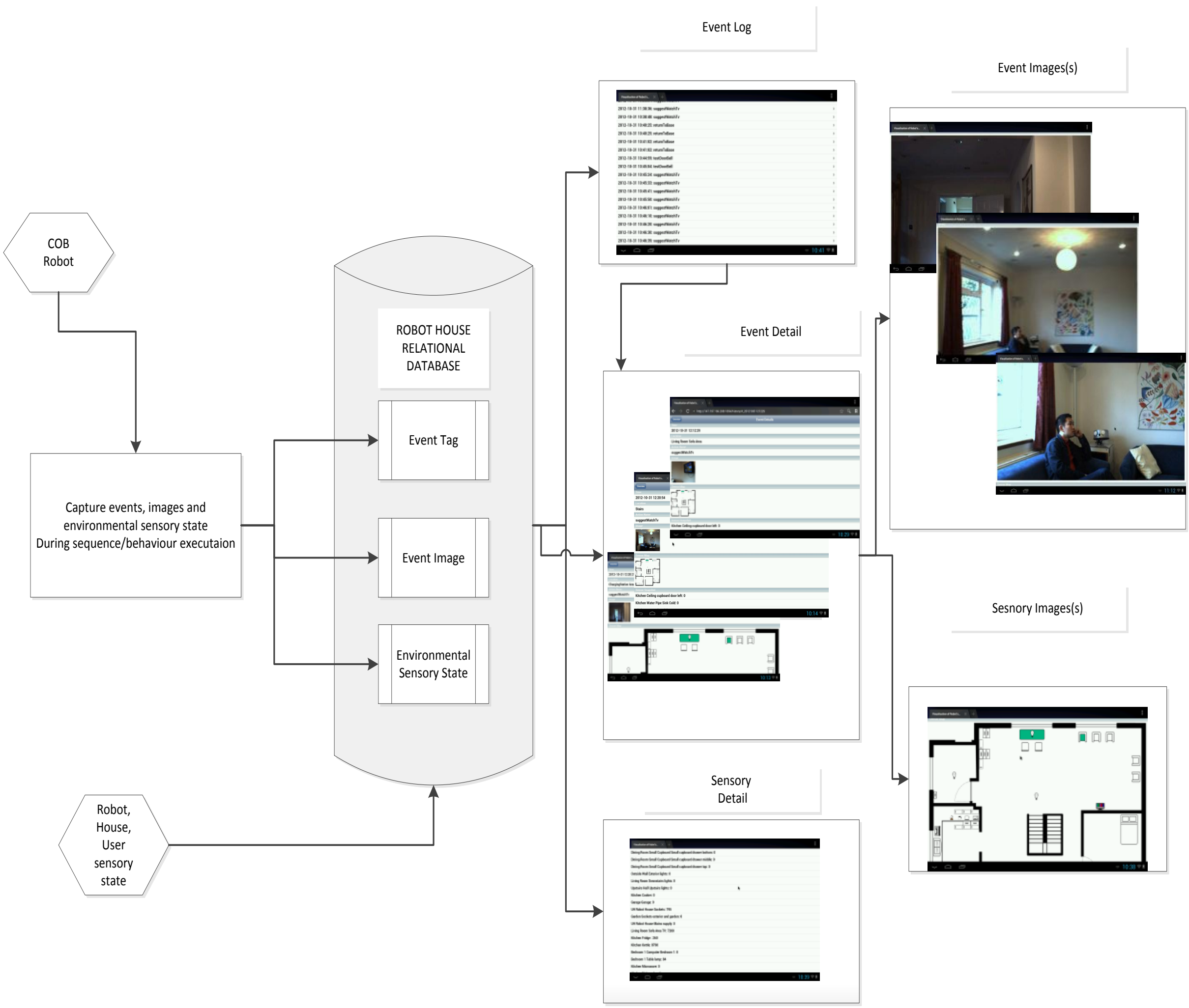


Figure 3.4.1 **Captured Memory Visualization Data**. The COB3 robot when executing behaviours has the facility to record images, sensory values and events. These events are triggered either singly by main behaviours, or by each sub-behaviour of a larger behaviour, or on a timed basis (e.g. every 5 seconds). Each event is stored in the robot house database together with its associated image and sensory history. These items can then be reviewed using the memory visualization interface (shown here running on an Android tablet).

Figure 3.4.2 **Visualization Event Log**. Each behavioural component or sub-component is tagged with its time of execution. Each tag is clickable to show the event detail image (see figure 3.4.3) and sensory state (see figure 3.4.4).

Figure 3.4.3 **Event Detail**. In this example a sequence of the 'suggestWatchTV behaviour is executing. Each event is displayed with the captured image and a schematic on the house sensory state at that time. Both of these items are 'clickable'. In this sequence the robot is seen proceeding from the charging station, through the house to the user, and then watching TV.

Figure 3.4.4. **House Sensory State Detail Expanded**. The green indicate sensory activity at the visualization point. In the example above the desk power and main sofa seat in the living room are 'on. Also the TV is active. This would imply that the desk computer was being used and that someone was seated in the living room probably watching TV.

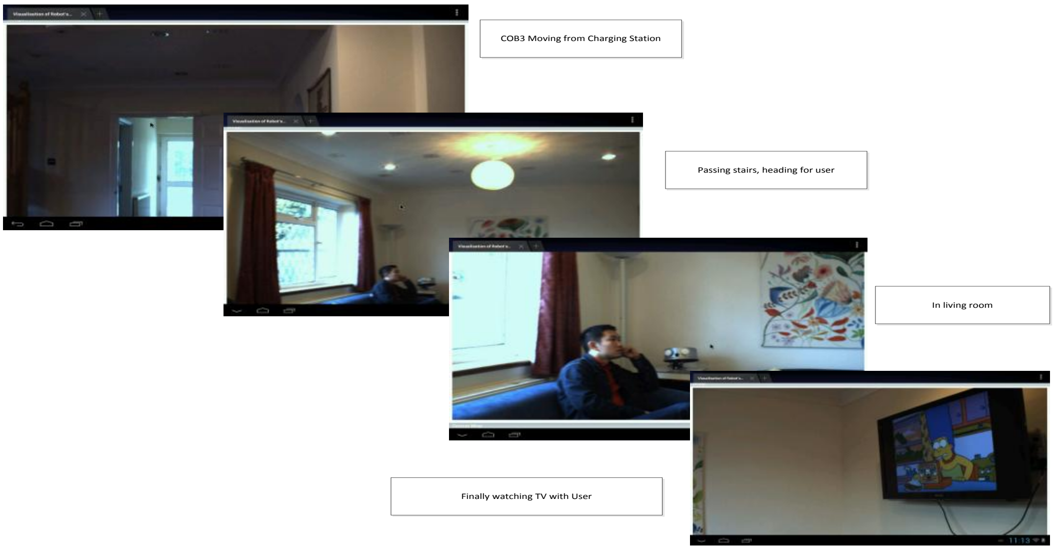
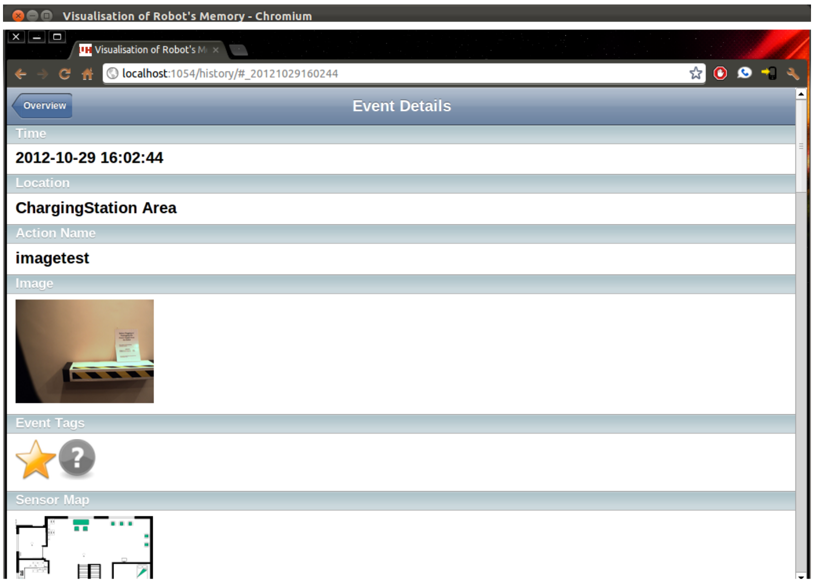
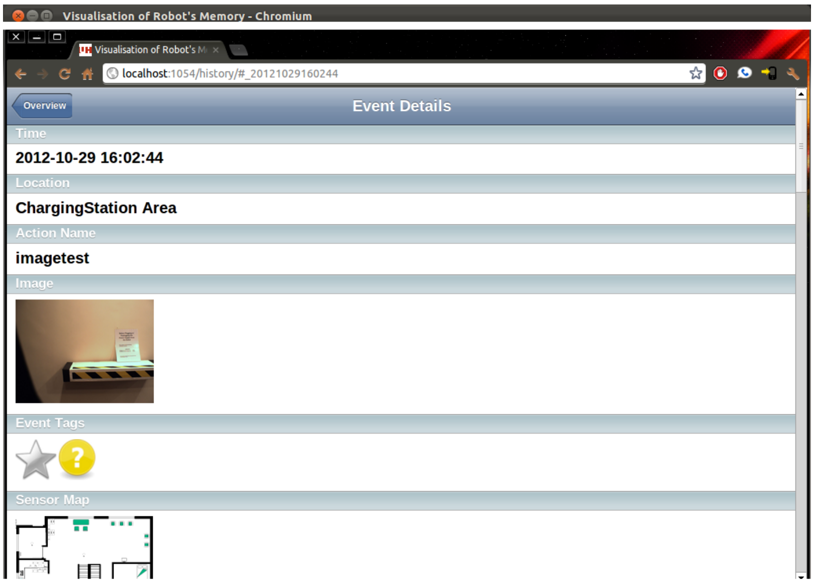


Figure 3.4.5 COB **Visualization Image Expanded**. The images captured by the COB3. Here the robot moves from its charging point, via the bottom of the stairs, to the user. We then see it watching TV.

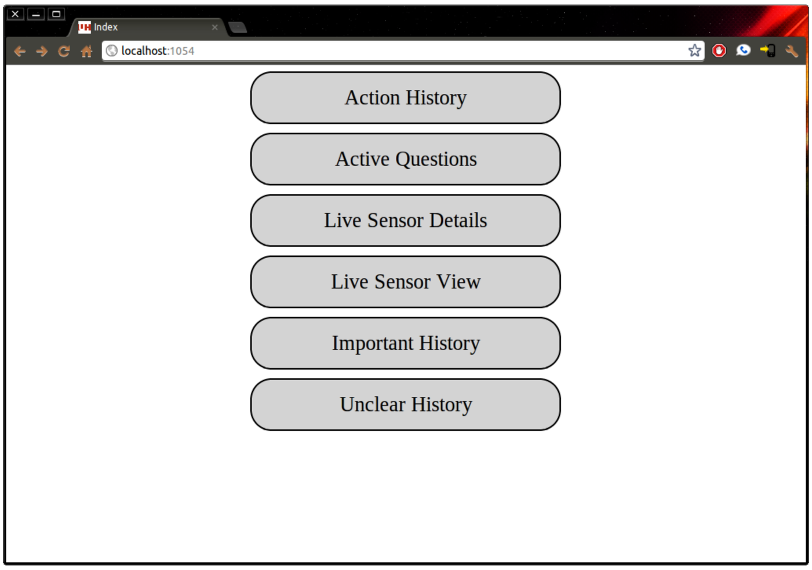
Figure 3.4.6 **COB Actions from an External Camera.** The same sequence as shown in figure 3.4.5 but from an external camera showing the COB moving from its charging station to the user and then watching TV together.



a)



b)



c)

Fig 3.4.7 **Tagging and Retrieval of Important or Unclear events**. Users can tag events as being important/interesting (star, diagram a), and/or they can label events that posed problems ("?", diagram b), e.g. when the behaviour of the robot was unclear, or it did not perform as expected etc. At a later stage the user is then able to specifically select and view these selective events (diagram c shows a very initial interface which will be improved in future), rather than being required to go through the complete interaction history that has been automatically logged by the system. Yellow colour indicates that the user has selected this tag for this particular event.

4 Discussion

Based on the initial implementation provided in the previous section, here we look into the potential and benefits of memory visualization and note issues that may exist due to current technical limitations.

4.1 Potential of the Memory Visualization System

Users may benefit from the visualization of a robot's memory in various ways. The obvious gain is that a user can look into past events and try to use their personal robot in different ways: Exploring the full functionalities of their robot, learning from previous mistakes and practicing the most useful features. For example, while inspecting the interaction history, the user may realize that the robot occasionally makes mistakes in distinguishing between two different objects that have very different functionalities but similar sizes and shapes (e.g. two rectangular, small black objects, one being a TV remote control and the other a mobile phone). This could help a roboticist to identify this as an area where the robot's object recognition capabilities need improvement. Or it could encourage a non-technical user to help the robot to disambiguate the information by not storing the two objects routinely in the same location, taking advantage of the (human and robot) co-learning paradigm. Furthermore, in assisting users who are likely to be forgetful and need frequent reminders in everyday activities, a robot's memory can serve as a cognitive prosthetic. However, users do not need to wear a camera or learn how to transfer or back up data from their camera to a computer because all they do is interacting with their robot whilst carrying out their normal activities at home.

In recent years HRI researchers working with elderly users have been adopting methods of co-imagination to allow users to share their personal images in order to generate social conversations between them [12]. Along that direction the role of a human moderator was later replaced by a remotely controlled humanoid robot. Researchers claimed that generating social conversation among these users can improve their cognitive health and elderly users participating in such social events can prevent or delay their dementia. Although the use of a robot in such research is different from the robot used in the ACCOMPANY project, it reveals that sharing personal stories and images can stimulate more social conversation in elderly users and thus improve their memory. Similarly, future research on storing, organising, retrieving and visualizing personal and meaningful information via a robotic companion could contribute to this area. Our system has shown a first step towards enabling users to tag events that are meaningful and/or personal to them, which could be extended in future towards system with an explicit narrative[4] representation of events.

[4] Note, the term 'narrative' in this deliverable specifically refers to activities of daily living as captured visually as sequential interaction histories in the robot's memory, which is a very limited, but in our project suitable. interpretation of the term but which differs from the much richer notions on narrative

4.2 Structured data

With recent advances in technology, it is much easier to create, record and store digital material. However, the management of such information is still extremely difficult. As reviewed in [10] and [11], there are issues faced by many PIM researchers regarding the structuring of the captured data – i.e. recording everything that happens in a person's life can raise concerns that 'clutter' may obscure valuable content and that information overload may occur, resulting in longer searching and browsing time. Thus better interpretation and visualization is required.

In our approach of using the COB3 to record HRI events, data captured by the COB3 is represented in a structure that is stored permanently in a central relational database, recording images, actions and the environmental state of both the Robot House sensors and the robot itself. This avoids the issues of managing raw sensory data and attempting to form separated events from them. Furthermore, the interface of data visualization allows users to clearly identify important events, for example, by date or other contexts, such as location and robot action; this means that the time required for browsing and searching for specific events can be reduced. As shown above the important and unclear/problematic events can be tagged and viewed selectively.

4.3 Challenges

Although advantageous in searching and browsing information, event structure in our computational memory is based on actions that the COB3 carries out, and such a definition of an event in long term HRI can be over-simplified as they are bound to the direct reaction of the COB3 based on the given sensory input (although these reactions can also be based on user preferences and requirements e.g. reminding the user that medicine needs to be taken at a certain time). To improve such situations, we believe richer scenarios and more contextual information will be needed to create better social dynamics recorded by robot's memory, allowing it to use such information to plan and act in real-life HRI situations. A key problem of this approach is that during long-term interaction, as envisaged in future scenarios where home care robots assist users over several months or years, a large amount of data will be recorded, and it will most likely become impractical for the users to search a considerable amount of information. Thus, the challenge remains on how to filter and organise the memories efficiently and according to the personal relevance and *meaning* they provide to the user. The solution taken at present, based on manual tagging as described above, presents a first approach that was feasible to realize in the first year of the project, While a detailed investigation into memory visualization goes beyong the scope of ACCOMPANY, future work could investigate how information on the state of the user (e.g.

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as used in the literature which emphasize the meaning and personal significance of events (e.g. Bruner [14] and other scholars).

physiological states, user behaviour and activities, explicit input provided to the robot via the GUI or other interface), the robot (e.g. states and goals of the robot), and information on the states of the environment could be used to only selectively store those events that are 'memorable'. Such an approach may be favourable from a user's perspective since it has similarity with how biological systems selectively store information, but it would mean that the stored interaction history will be fragmented, and one would lose the possibility to inspect the complete record of the interactions, which may be desirable from the perspective of secondary users (who may e.g. be interested at some point to view as much information as possible about how a user interacted with a robot on a particular day) and providers of robots (keeping a record for safety and debugging purposes etc). Thus, a careful balance has to be found between aspects of memory and memory visualization as they are presented to the user, and aspects that are being kept as an automatic record of the interactions. Clearly, ethical considerations are important in the long-term use of robot long-term memory and memory visualization. For example, users need to be aware that the events they experience with the COB3 may be captured and stored in digital media. This means that they could be given the right to switch off the memory module of the COB3 for reason of privacy, although secondary users and other stakeholders may favour a complete record for safety, medical and other reasons. Typically elderly users may want to avoid letting other people know about their health conditions and also everyday events that they may feel embarrassed about. Therefore digital records of can be sensitive and these issues need to be considered when designing the memory storage of a personal companion robot[5].

5 Conclusion

The work presented in this deliverable represents completion of task T3.3. In the ongoing ACCOMPANY project, we will seek feedback from our user groups on the proposed memory visualization feature as described in this deliverable. We are particularly interested to find out if it could help the user's recollection of past events and how useful they may find this feature in their daily life.

Investigating the research topic of narrative generation and visualization of memory in great depth goes beyond the scope of this 3-year project. The system presented in this deliverable is a technologically straightforward approach to this task which we nevertheless hope will be appreciated and thus contribute to the acceptance of the ACCOMPANY system by our target user groups.

In this deliverable we illustrated the initial implementation of a robotic companion's memory visualization feature and pointed out the potentially useful aspects as well as challenges and

[5] Furthermore, users may not want any visual recordings on certain days due to personal choice and preferences.

avenues for future research. The basic concept of such a system has been supported by positive results from users in a previous study and user feedback on the re-developed version presented in this document will also be sought in the ACCOMPANY project. The system presented in this document will be further integrated as one feature of the robot's computational *long-term memory*, which is the core research focus of WP3 (T3.2).

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