Memory Models for Intelligent Social Companions

Mei Yii Lim

Abstract Memory gives us identity, shapes our personality and drives our reactions to different situations in life. We actively create expectations, track the fulfilment of these expectations and dynamically modify our memory when new experiences demand it. Yet up to date, many important social aspects of human memory to artificial intelligent social agents have not been given much attention. Thus, this article is going to review on the current state-of-the-art of memory models for social companions, particularly on memory aspects that have been explored and proved useful and other potential memory aspects that would be beneficial if included.

1 Introduction

The term 'Companion' has recently gained popularity in the field of artificial intelligence and robotics. In the recent decade, the number of 'Companion' related projects has been mushrooming including

- COGNIRON[1], aiming to develop cognitive robots that interact with humans, able to perceive, decide, communicate and learn in an open-ended way
- Companions[2], that has developed virtual conversational companions aiming to change the way people think about human-computer relationships and the Internet
- LIREC[3], that focuses on establishing a multi-faceted theory of artificial long-term companions that can establish long-term relationships with humans, em-

Mei Yii Lim
School of Mathematical and Computer Sciences, Heriot-Watt University, e-mail: M.Lim@hw.ac.uk

[1] http://www.cogniron.org/final/Home.php
[2] http://www.companions-project.org/about/faqs.cfm
[3] http://www.lirec.eu

bodies this theory in robust and innovative technology and experimentally verifies both the theory and technology in real social environments
- SEMAINE[4], with the objective to build a Sensitive Artificial Listener with social interaction skills needed for a prolonged conversation with a human user
- SERA[5], that aims to study social interaction between users and a robot in real life situations

It is sometimes unclear what a 'Companion' really is. In the listed projects, the term 'Companion' is used to refer to either a robot or a virtual conversational agent that possesses a certain level of intelligence and autonomy as well as social skills that allow it to establish and maintain long-term relationships with users. The 'Companion' will be accessible to users over a long period of time, interact with users in a friendly way, assist users in real life situations and help them make sense of information. All these projects emphasise the importance of cognitive and social skills. This type of 'Companion' that I termed 'Intelligent Social Companion' (ISC) is the focus of discussion in this article despite the fact that Tamagotchi, virtual pets[6] and dolls such as Prima Puel[7] are sometimes suggested as 'Companions'.

The emergence of ISC technologies is turning simple human-computer and human-robot interaction into relationship building between technological artifacts and humans [9]. This means that an ISC will be more than just a tool but a technological artifact that takes into consideration users' wants and needs and has the ability to form mutual attachments with users. However, due to the infancy of the field, ISCs that are able to satisfy these functions are yet to be developed. Current ISCs still have limited social intelligence and interaction capabilities owing to the lack of life-likeness and proneness to repetitive behaviour that jeopardise its believability and naturalness.

In order to establish long-term and pleasing relationships, social and emotional investment is very important [15]. According to Fiske [39] there are five unifying motives for the establishment and maintenance of successful long-term relationships:

- **Belonging** – need for strong, stable relationships
- **Understanding** – need for shared meaning and prediction
- **Trusting** – need for viewing others as basically benign
- **Controlling** – need for perceived contingency between behaviour and outcomes
- **Self-Enhancing** – need for viewing self as basically worthy or improvable

To satisfy these motives, an ISC will need to be able to provide a personalised interaction experience, exhibits its own internal states, understand users' emotional states, act reliably and appropriately, performs its tasks autonomously and effectively and increase users' self-esteem under suitable circumstances. This implies the need for an ISC to remember users' preferences and make use of this information

[4] http://www.semaine-project.eu/
[5] http://project-sera.eu/
[6] http://virtualpet.com/vp/
[7] http://medgadget.com/archives/2005/04/primo_puel_doll.html

in sensible and plausible ways to ensure coherent interaction throughout the relationships. In other words, there needs to be a means to organise relevant interaction history in such a way that it is retrievable and reusable under appropriate circumstances during subsequent interactions. For that reason, memory is vitally essential for an ISC as in any social being. Imagine life without memories. We would have no recollection of our past nor anticipation of the future. We would live forever in the present moment, ask the same questions or perform the same actions over and over because we would not be able to remember previous events. The same applies for ISCs.

ISCs must have the ability to perceive, respond, react and express appropriate behaviour so that interaction with humans can be more believable, natural, enjoyable and lead to long term relationships. A memory component will allow an ISC to store, retain and recall information as well as experiences to aid sensing, reasoning, learning, sharing of information with others and making sense of anything happening around it because "understanding the world means explaining what has happened in it in a way that seems consonant with what you already believe" [86]. Without this 'illusion of life', satisfying interaction with ISCs will quickly fade due to unmet expectations about their behaviour and intelligence.

Following this argument, the core topic of this article is the memory component for ISCs with the main interest on the social aspects of human memory such as emotional memory [44, 82] that stores emotionally significant events and episodic memory [93] that stores an individual's experiences and experiences of others. These memories will enable ISCs to share their experiences with users and hence to socially and emotionally connect with them [73]. Through emotional sharing of experiences, the interaction will seem more believable and engaging and the ISCs will appear more natural to users [12]. It will also provide a reflection of "self" giving users impression of personalities in the ISCs. Furthermore, ISCs that remember previous encounters will be able to learn from these experiences and maximise the potential of the cognitive system through recall of appropriate information in a timely manner.

The next section provides an overview of the commonly accepted theories on human memory. This is followed by a quick run through of existing memory models or architectures for artificial agents that are inspired by biology, neuroscience, cognitive science or psychology. A discussion about what is still lacking from the current state-of-the-art in social memory modelling is then presented before the concluding remark.

2 Human Memory

Up-to-date, there is still no consensus about how human memory works [30, 58]. In the late 1960s, a two-component memory system consisting of a long-term memory (LTM) and a short-term memory (STM) was proposed [6]. An influential model of the time is the one by Atkinson and Shiffrin [4] who proposed that human memory formation involves a three-stage sequence: encoding, storage and retrieval involving sensory memory (SM), STM and LTM. Information from the environment is assumed to flow through a series of very brief sensory memories into a short-term store with limited capacity [68]. Attention plays a vital role in forming memories and as people get older, their attention starts to flicker which may explain why they forget more easily due to encoding flaws [46].

Information from STM is later transferred into LTM through repeated exposure and elaboration [27] or forgotten. Barlett [8] suggests that our memory is dynamic and is reconstructed continuously where new information is remembered according to how it adapts to existing knowledge and schemata. This reconstructive view is supported by Schank [85] and Alba and Hasher [1]. Schank suggests that we modify memory structures on the basis of mismatches between old and new information and except under very unusual circumstances, memory traces representing highly typical events in a particular episode will be forgotten while atypical pieces of information are selected to receive special representation in memory. Alba and Hasher [1] proposed a prototypical schema theory of memory, assuming the operation of four central encoding processes: "selection, abstraction, interpretation and integration". In addition, a fifth process, reconstruction, occurs when an individual attempts to reproduce a memory episode.

Although remembering is useful, if we are to store every incoming information, we will have information overload, difficulty in organizing the information and difficulty in focusing on one piece of information at a time. Hence, forgetting is important to prevent stale information from interfering with fresh information [2]. Some of the commonly accepted theories of forgetting include decay theory [19, 2] (memories fade away with time or task), reconstruction process [1, 8, 85], interference [16] (information encoded later interferes with information encoded earlier – retroactive interference or information encoded earlier interferes with information encoded later – proactive interference) and repression [42] (memories are unconsciously blocked from awareness). When it comes to recalling memory, contextual cues are crucial [95] and retrieval is most effective when a match exists between encoding and retrieval conditions [14].

STM memory or "working memory" in Baddeley and Hitch's [7] term is assumed to comprise a central executive component assisted by a phonological loop, a visuospatial sketchpad and an episodic buffer [5]. The phonological loop plays an important role in processing verbal information while the visuospatial sketchpad is responsible for spatial orientation and visuospatial problems solving. LTM on the other hand can be divided into explicit (or declarative) and implicit (or non-declarative) components [6]. This view is consistent with LeDoux's [57] proposal that our brain contains a variety of different memory systems that work in parallel to give rise to independent memory functions. Implicit memory stems from previous experiences and aids us in the performance of tasks without us being consciously aware of it [84].

On the other hand, it is generally accepted that conscious explicit memory can be further separated into semantic and episodic memory [93, 94] although there is another view suggesting that semantic memory is simply a collection of episodic memories without detailed contextual cues [89]. Semantic memory is a store for information about the world and the way it functions while episodic memory is a memory of events subject to time and space that keeps track of progress of active goals as plans are being executed. Episodic memory recall is not generative and involves mental time travel, permitting an individual to re-experience past events although the intensity of experience might not be as strong.

According to Conway [26], episodic memory comprises of abstract conceptual and sensory-perceptual details of recent experiences that perish rapidly if not linked to autobiographical memory [73], a more permanent type of memory about 'self' which can persist for hours or even lifetime. Autobiographical memory is a semantic store about one's life that retains significant knowledge of the self at three different levels of abstraction: life periods, general events and event specific knowledge in increasing level of 'near-experience' details. Its main purposes are: self (personal identity), social (memory sharing) and directive (guiding future actions) [13]. It is constructive, evolves over time and allows interpretation of new events in light of past experiences – a memory of the past and future [74] – but does not necessarily give rise to recollective experience unless the recall includes active episodic memories. It underlies our story-telling and history-making narrative activities and is an important aspect of social intelligence that allows formation of social relationships and communication [73].

Recent neurological findings reveal that memory contains not only data or information but emotions too [23]. The emotional intensity of an event plays a key role to the endurance of the event in memory [44]. As a result, emotional events occupy a large portion of our LTM relative to neutral or everyday events. However, emotional intensity and memory strength is not necessarily linear as in the case of trauma where emotional arousal can sometimes impair memory [81] but this issue is out of the scope of this article. Emotional memory can also be divided into explicit and implicit components. Explicit emotional memory is mediated by the hippocampus and related cortical areas, whereas implicit emotional memory involves the amygdala and related areas [57]. The hippocampal system lets us remember the details of a situation, whilst the amygdala system produces stimuli that activate our body chemistry for the emotional situation. When we retrieve an emotional memory, we relive the old events [23] similar to autobiographic memory recall of event specific knowledge which implies that the part of our autobiographic memory that allows recollective experience is made up of emotional memories. This also means that episodic memories that are consolidated into autobiographic memory are those with emotional significance.

As time passes, an individual's reliance on episodic memory of emotional experiences that link recall to specific details of a situation reduces while reliance on semantic cues that link recall to general beliefs and theories increases [83]. This is consistent with Levine's view [59] that memories for emotional responses are partially reconstructed on the basis of current appraisals of events. In general, emotions that were inconsistent with the current appraisal were likely to be underestimated during recall whereas emotions that are consistent with current appraisals were likely to be recalled accurately or overestimated. Additionally, Forgas [40] found that recall and recognition of mood-consistent information are superior to mood-inconsistent information. This is supported by the mood congruence effect that suggests we pay attention to information or events that are consonant with our emotional attitude [43].

3 Computational Memory

Artificial intelligent agents researchers have begun to realise the importance of human-like cognitive and social capabilities for their agents since the emergence of the affective computing field [80] in the late 90s that switched the focus of intelligent systems from mere problem solving to the social and emotional dimensions of computer technology. Even a decade prior to the explosion of the affective computing field, Minsky [69] made a related statement regarding machine intelligence – *"The question is not whether intelligent machines can have any emotions, but whether machines can be intelligent without any emotions"*. With this switch, the vision for intelligent agents extends to the fulfilment of human cognitive and social needs. Dautenhahn [29] argues that the better computational agents can meet these needs, the more familiar and natural they are, and the more effectively they can be used as tools.

Earlier computational memory architectures that focused on building large database systems and designing efficient search methods which functioned only in limited domains are insufficient and need to be replaced by something more robust and flexible. Recent research (e.g. [50, 34, 18]) has shown that in order to establish natural and engaging long-term relationships with human users, intelligent agents or robots will need human-like memory structures and processes to meet user's expectations regarding life-likeness, intelligence, responsiveness and to overcome rigid sets of repetitive behaviours. Hence, this section reviews some of the work done thus far in the area of human-memory modelling for artificial agents. Many other interesting memory models or architectures exist but here the focus is on those that are inspired by biology, neuroscience, cognitive science or psychology. Some of these models or architectures have evolved over the years and an effort has been made to ensure that the presented information is the most up-to-date.

3.1 Computational Memory for Non-Social Agents

Although some early work looked at simple episodic memory systems (e.g. [66, 97]), it remained a neglected area in the symbolic AI community [76] until the last few years. One of the earliest notable work is the one by Ho and colleagues [51] who implemented an autobiographic memory that stores significant episodic events in Artificial Life agents. Ho [49] carried out experiments to compare different memory control architectures in single-agent and multi-agents scenarios under different virtual environments settings. The results demonstrated that autobiographic memory enhances an Artificial Life agent's survival skills through the ability to backtrack previous encounters and remember significant events that changed its behaviour as compared to a purely reactive memory model where no previous interactions were recorded. In the multi-agents setting, group performance was found to improve as frequency of experience sharing increases among autobiographic memory agents.

Dodd [33] implemented a STM, LTM and a Working Memory System for his Intelligent Soft Arm Control, humanoid robot. The STM stores information about the current environment. The LTM consists of a procedural memory that stores learned behaviours, a semantic memory that holds semantic and perceptual knowledge and an episodic memory that records past experiences along with salient information from the Emotion Agent in a time-indexed format. The more salient an episode, the longer it will persist in the memory. The Working Memory System holds task-specific STM and LTM elements that are passed to the cognitive processes during a task and are updated continuously as new situations arise. Each memory type uses a different retrieval method and has its own limited capacity Working Memory. An episode in the episodic memory is defined by a goal and retrieval is performed based on the relevance, recency, novelty, importance and emotional saliency of the episode to the current situation. Thus, emotional information ensures the retrieval of the most appropriate episode and allows the system to remember information in the distant past that was extremely salient and recent information that was not very salient. The retrieved episode is then used by the planner to generate future actions.

Nuxoll [76] attempts to create a task independent architecture of episodic memory that can be used to support many different cognitive capabilities embedded in a general cognitive architecture, Soar [75]. Soar has a working memory which encapsulates the agent's entire state and a procedural memory, represented as production rules that determine the agent's responses in the environment. The episodic memory is effectively a snapshot of the working memory taken at the time of encoding. Once an episode is created, it remains in the memory forever. During retrieval, an agent uses information in its working memory to create a cue that will be matched against episodic memory episodes. It then uses the effect of the best matched episode to evaluate the best action for the current situation. Two testbeds were used to test the episodic memory: Eaters, a Pac-Man like environment and TankSoar, a two-dimensional, tile-based implementation of a first person shooter game [78]. The author found that the effectiveness of an episodic memory system is dependent on the matching algorithm that is used to select the best match for a given memory cue. Since the agents' decision is based on the retrieved episode, a wrongly retrieved episode would lead to poor decisions. Additionally, the impact of an episodic memory system on storage and processing time was explored – the constraints on retrieval time as the number of episodes increases was identified.

Similar to Nuxoll, Tecuci [91] proposes a generic reusable episodic memory architecture that can be utilised by a variety of applications. The author suggests a set of requirements in terms of memory encoding, storage and retrieval that any memory module should follow and proposes a generic representation for events and relevant retrieval algorithms. Using the set of requirements and proposed representation and retrieval mechanisms, a memory module was implemented and evaluated. The results show that the memory module is scalable (able to store an increasing number of events without decreasing performance drastically), efficient (both storage and retrieval) and accurate (retrieval of relevant facts according to situations). It is undeniable that these aspects are important for intelligent systems but these are not the only crucial criteria for ISCs interacting with human users over a long period of time. Highly accurate and efficient retrieval may not be necessary in many situations involving believable social agents. After all, human memory is subject to flaws and is by no means 'perfect'. In many situations, these agents will need to interpret new information based on existing knowledge which might lead to inaccurate recall.

3.2 Computational Memory for Social Agents

While the above mentioned work focuses on agents that do not require social skills, Ho and colleagues developed an autobiographic computational memory model inspired by human narrative discourse units and the reconstructive nature of human autobiographic memory for intelligent narrative agents [50]. The authors argue that the answer to long-term believability in intelligent agents that interact with humans repeatedly is the existence of a long-term autobiographic memory. This type of memory will enable companion agents and narrative agents to learn from previous interactions and to avoid repetitive discourse. Additionally, it will ensure behaviour coherency in the agents since life stories are fundamental to coherency in human beings [64]. This stance is supported by Bickmore and colleagues [11] who carried out an evaluation on users' perception towards agents with autobiographic memories. The results reveal that an agent that tells human autobiographic stories from a first person perspective, although may seem deceiving actually leads to improve engagement in the users.

The testbed for Ho and colleagues' autobiographic computational memory was FearNot!, an anti-bullying software created by the EU project eCIRCUS[8]. The memory model was integrated into the FearNot! agent mind architecture, FAtiMA [32]. As stories unfold within different bullying episodes, the agent records occurring events in a chronological order along with emotional impact of the events generated by the appraisal processes. When an episode ends, an abstract is generated which summarises the episode based on the event with the highest emotional intensities. The agent can then use this summary to create its life stories for narration to the users [31].

Heading in similar direction, de Campos [22] proposes a memory model for social companion that does not only store its personal experiences but the user's too. In her implementation, the knowledge based of the companion consists of 3 subgraphs: lifetime periods, general events and event specific knowledge which are interconnected, at the same time can be accessed separately. The main aim of this

[8] http://www.e-circus.org/

work is to create a shared experience between the users and companions. By storing the user's experiences, the author hopes that the agent can be more attentive to the user's goals and can utilise previous interactions information to guide future actions, hence sustaining its relationship with the users. A user evaluation shows that having knowledge of the user's life contributes to a higher perceived intimacy and companionship between the agent and the user.

In a more recent work, Ho and colleagues [52] propose an initial complete memory model for social companions with different embodiments including virtual agents and robots. The model consists of a low-level sub-symbolic memory and high-level long-term and short-term memories. The low-level sub-symbolic memory handles sensor- and actuator-related information using a blackboard architecture [48] and translates sub-symbolic information into symbolic data for further processing. The LTM composes of a semantic world knowledge component, an autobiographic memory component and a General Event Representation component. The world knowledge component is a store of semantic knowledge. The autobiographic memory holds episodic events taking place in the companion's environment while General Event Representations can be perceived as memory schemata that provide expectations about what the agent will experience. The STM on the other hand consists of STM buffers and a Working Memory. The STM buffers temporarily hold a limited set of recent events while the Working Memory holds common facts about objects, locations, people and so on essential to the event reconstruction process. A selection process takes place in the STM, which determines what should be retained in the LTM allowing the companion to remember only significant and relevant information.

A spreading activation [3, 67] based memory retrieval is utilised to allow the companion to connect different memory events and generate appropriate responses under different interaction circumstances [62]. This answers the question raised by O'Hara and colleagues [54] on associative memory – how can we store symbolic data in such a way that it supports associative recall? The spreading activation mechanism aids appraisal and decision making processes, particularly when an educated guess or prediction is required because it supports retrieval of events that do not match the current perception exactly but are relevant to the situation at hand. It also enables the companion to answer users' queries and is useful for narrative generation. Unlike Burkert and colleagues' model [21] (discussed next), the propagation can be across multiple events. Moreover, in order to create a more socially competent ISC, adaptability to the user preferences and motivated forgetting are incorporated [61]. To maintain long-term relationships, it is important for the companion to be adaptive to users' interaction styles and preferences. By doing so, it will be able to predict and respond appropriately to the users' requests. On the other hand, the main aim of motivated forgetting is to overcome privacy issues.

Brom and colleagues [18] attempt to create a full episodic memory model for virtual characters storing more or less everything happening around the agents. The memory design is based on a connectionist model and is composed of a three-lobed neural network [21]. The core lobe is the long-term episodic memory storing past episodes containing a forest of AND-OR trees of performed tasks. This lobe is surrounded by other timing related lobes. The system can automatically form time concepts by associating time with contextual information, hence allowing the agent to answer vaguely specified time-cued questions. Recall is performed through a spreading activation network and currently, only propagation to direct neighbours is possible. As time passes, unimportant details of episodes and events with low emotional intensities are forgotten. Moreover, the memory model allows episodes blending and is error-prone analogous to inaccuracies of human memory.

Recently, this concept has become a hot topic of discussion among agents researchers. The question has been raised whether or not to give agents a 'forgetting' capability. Do we really want agents that forget? Current research shows a tendency towards the answer 'YES'. Vargas and colleagues [96] argued that 'forgetting' is essential for the creation of ethical companions. Burkert and colleagues [21] suggest that people prefer less precise time references over exact time specification by virtual agents. Nuxoll and colleagues [77] show that forgetting is an important component of any episodic memory because it helps to improve performance of the agents by keeping memory size under control. Another ongoing study in a similar vein is the one by Bransky and Richards [17] who try to compare the impact of different levels of recall in agents interacting with human users. Consequently, researchers have started to implement memory models with forgetting mechanisms and the common algorithms include time-based decay [25, 21], forgetting redundant or insignificant information [18, 61] and activation-based forgetting [60, 18, 77].

Other social memory models include [10, 79, 65]. Bickmore and colleagues [10] developed a 'virtual laboratory' for longitudinal studies of human-virtual agent interaction which incorporates a standing group of participants who interact on a regular basis with a virtual agent for an indefinite period of time. The agent runs on their desktop computers and possesses persistent memory represented as an episodic store. The memory records details of all past interactions with users as well as specific facts to aid future conversations. Ogino and colleagues [79] show that long-term episodic memory with attributing emotions can facilitate human-robot interaction in a simple Peekaboo communication task by allowing a virtual robot to predict rewards from human users. On the other hand, Mavridis and Petychakis [65] present a set of desiderata for companions' memory systems together with two case studies involving an interactive manipulator robot arm and a social mobile robot.

3.3 Emotional Memory for Recollective Experience

Lim [60] implemented an emotional memory for her virtual tour guide system that is capable of providing a customised narrative based on users' interests and perspectives. The emotional memory which is part of the guide's LTM is made up of the guide's past experiences and ideological perspectives. During the tour, when the guide retrieves its emotional memory elements, it re-experience the event by expressing the emotional impact of the retrieved event. The emotional recollection is achieved through a concept called Emotional Tagging [81]. The recollective experience might be at a lower emotional intensity as compared to the original encounter due to the influence of the guide's current internal states. An emergent emotional model is applied to perform this blend before the emotion is expressed by the guide through a two dimensional face. A similar approach can be found in [24].

A more recent work by Gomes [45] attempts to create a model for retrieving emotionally relevant episodes in agents. The proposed retrieval mechanism involves two phases: ecphory and recollective experience. To trigger retrieval, cues which are groups of perception variables are used. When these cues are compared to memory traces during ecphory, perceptual distances between cues and traces are calculated. The closest trace is then selected for recollective experience through a reappraisal process resulting in emotions and mood expressions. An evaluation that has been carried out in a game environment shows that agents equipped with this retrieval mechanism are perceived as more believable compared to agents without similar capability.

Francis and colleagues [41] proposed a memory architecture with embedded emotion models to aid the development of agents for long term interaction. By having the emotion model integrated into the memory, when an agent encounters a previously experienced situation, it also retrieves the emotional vectors associated with that experience. The evaluation system can then modify these emotional vectors to incorporate it into the agent's current states, hence allowing the agent to exhibit emotional re-experience. This approach provides users with an impression that the agent had internally generated behaviour rather than a rigid creature that react in a fixed way to external stimuli.

4 Potential Improvements

Now that we know the state-of-the-art of memory research for artificial agents, we are going to look at the implications and the current deficiencies of the field.

4.1 Compatible Theories

Social and episodic memory modelling is still at its infancy. Although numerous studies have been performed over the past 10 years, one of the hallmarks of science has yet to be achieved. This is probably due to inadequate data and theories to form the basis for a detailed memory model, especially on the social aspects of human memory. Social agents researchers will have to rely on what is available and decide for themselves the most suitable theory or theories to apply. I am not suggesting that we should mimic the exact human memory processes but to exploit useful human memory functions based on tasks demand of different application areas. To address this issue, the Memories for Life project[9] and the Foresight Cognitive Systems project[10] are demonstration of efforts to bring together a diverse range of academics to understand how memory works and to develop technologies to enhance it.

4.2 Context- and Social- Awareness

Sadly, technology has more than often been inserted into social situations without being given a proper consideration about how people might interact with it [54]. Although the arrival of companion agents could be beneficial, particularly for vulnerable user groups such as the elderly (e.g. Paro[11] has been certified by Guinness World Records as the World's Most Therapeutic Robot) and the disabled (e.g. Care-O-bot[12] acts as an interactive butler to assist humans in their daily life by providing adaptive walking aids, picking and transporting objects for users), their appearance in our lives is not without concerns. Researchers have been debating about the potential ethical danger of these artifacts [88, 90] and this has led to the emergence of the Roboethics discipline [98, 99].

Since the arrival of ISCs has now become a certainty in the coming years due to the desirability and possibility of some form of long-term companionship with these ISCs [100], it is important to think about the role we want ISCs to play and how we can protect ourselves from any undesirable effects should it become necessary. Currently, these ISCs are lacking context- and social-awareness. The main concern in terms of memory is regarding the type of data these ISCs are going to record, how this data will be processed and later used. Being able to store and recite information and previous experiences is not enough. ISCs should know when, how and to whom the information can be disclosed. So, some of the questions yet to be answered include:

- How do we design ISCs that know what and when to record information?
- How do we design the memory model in such a way that it can process the information in ethically acceptable ways?
- How do we ensure that the information is used in the appropriate social context?
- Should we allow ISCs to disclose recorded information to someone other than the owner of the information?
- How do we balance the autonomy and control between the ISCs and users regarding the recording and use of information so as not to jeopardise interaction experience?

These questions need to be answered if we would like the ISCs to be accepted because people are generally skeptic about the future role of social agents in society

---

[9] http://www.memoriesforlife.org/

[10] http://www.bis.gov.uk/foresight/our-work/projects/published-projects/cognitive-systems

[11] http://www.parorobots.com/

[12] http://www.care-o-bot.de/english/index.php

[37]. As mentioned in the introduction, the establishment of long-term relationships relies heavily on trust and control. Without these measurements, users will feel intimidated when interacting with ISCs and the easiest way out is probably to avoid interaction with these artifacts altogether. This would be unfortunate given the potential benefits of these ISCs. Even though Lim and colleagues [61] addressed some privacy issues through motivated forgetting, this work is at a preliminary stage. A more thorough investigation into how ISCs memory model may handle trust and confidentiality issues is essential if these ISCs were to interact with the human users whether for a short or a long period of time. Undoubtedly, real requirements for ISCs can only be determined if users are actively involved in the design process because users satisfaction is central to the success of the end result [56].

4.3 Reliability and Robustness

Currently, ISCs still do not exhibit reliable behaviour in real-time especially in response to the highly dynamic behaviour of a human interaction partner. Although many studies demonstrated engagement and believability in interaction with artificial agents, these results are flawed by the experimental setting which is restricted to lab environments and hence is not scalable when it comes to natural setting.

In lab environments, it is usually not possible to carry out long-term studies and the feedback of participants is very likely to be confounded by the less than natural setting. Such sessions cannot provide us with the information we need about for instance the robustness and the memory requirements of the ISCs over a longer period of time in everyday, natural and human-centred contexts. Without real interaction data over an extended period of time, it is very difficult to predict how memory storage and processes will level up to tasks.

The investigation on interaction of artificial agents with humans in natural social setting has only been sparsely attempted. Some examples are studies by: Bickmore and colleagues [11] who evaluated an online health advisor; Kopp and colleagues [55] who employed an Embodied Conversational Character as an interactive information system in a museum; and Lim and colleagues [63] who carried out a Wizard of Oz experiment of their agent SARAH in a common area of a university department. The results of the two later studies reveal the agents' incompetence to endure in natural environment due to lack of engagement from the users. Thus, researchers should really start considering long-term studies in natural setting so that ISCs design can be more robust and reliable.

4.4 Self-Identity

One of the reasons for lack of engagement with current ISCs could be due to the lack of a sense of 'self-identity' in the agents. Most of the time, users are not provided with information about the agents' ability, interests, role and so on. As Bickmore and colleagues found out, autobiographical life stories are important for engagement [11]. Without a back story, users might associate wrong expectations to the role of the agent. Nass and Moon [72] found that humans tend to fill the ambiguity of interaction norms with social agents by applying human social norms if the agents appear human-like as in the case of most ISCs. This might have led to the "uncanny valley" experience in the users since the agents do not live up to these expectations [71].

In order to overcome this problem, an ISC will need to be given a plausible life story consistent with its role and functions. Storytelling is an important aspect in human-human communication and social interaction [20]. It has been used throughout history to organise information in ways that are comprehensible, engaging and enjoyable. We create and recite stories as we present our life experiences and since stories are presented in context, they enable others to remember the information more easily. However, care has to be taken to ensure that these stories comply with cultural rules [35], for instance avoiding topics that are usually regarded as sensitive including money, the own body, personality and sexuality.

By giving ISCs interesting or funny personal background stories, the interaction with users can be improved and ambiguities about their knowledge and capabilities can be reduced. It might also lead to a sense of belonging, understanding and even trust as users get to know the ISCs better. According to Hymann [53], emotional and personal information sharing can lead to the development of social bonds. Just imagine talking for the first time to a stranger, initially the conversation is kept to superficial topics such as the weather or news items. As you get acquainted with him/her, the conversation will switch to something more intimate. The same applies to ISCs.

Here, we can exploit the full potential of the autobiographic memory in ISCs since one of its main functions is defining the 'self' [13]. Thus far, it has only been used to store past experiences to be recited later. With the inclusion of background stories, ISCs will be able to associate newly acquired experiences with their existing stories to create even more interesting narrative that can be told at the appropriate moment in context analogous to humans' recall and storytelling capabilities – we are usually reminded by similar events, those close to previously experienced phenomena [85], hence, creating an illusion of life and intelligence.

4.5 Adaptability

Learning in agents remains an unsolved problem due to the difficulty in designing agents that comprehend symbolic data like humans do. This has led to inflexibility in agents behaviour. One potential solution to this problem could be applying the reconstructive nature of memory. None of the research thus far has looked at this aspect despite the fact that it is the most important attribute for knowledge regulation in humans as discussed in Section 2. Although Ho and colleagues [52] propose an event reconstruction process, it has yet to be implemented and no detail of the design has been given thus far.

We constantly reconstruct and adapt our memory to new knowledge and experiences in order to ensure a continuous existence of our being in this dynamic ever changing world. Without this ability, we will not be able to cope with uncertainties and threats posed by different circumstances in our daily life. According to the theory of cognitive dissonance, "the presence of a cognitive inconsistency of sufficient magnitude will evoke a negative emotional state that will motivate cognitive work aimed at reducing the cognitive inconsistency" [38] and it is the reconstructive nature of memory that allows us to update our beliefs to overcome this inconsistency so that we can adapt our behaviour easily when situations require [47].

ISCs if equipped with a reconstructive memory will have an increased learning and adaptability prowess. They will be able to respond to novel situations more easily through exploitation of existing experiences. The ISCs will be able to figure out which bit of previous knowledge and experiences is important and can be reused to address the current problems and subsequently update its memory with this newly obtained experience. These ISCs will be able to sense and reason beyond the current perception by using relevant previous experience to make predictions about the likely outcome of its potential actions. Memory reconstruction will also help the ISCs to analyse its own behaviour and behaviour of others and how these change over time to create a better model of others, at the same time improving its own behavioural response. Through remembering users preferences and updating them continuously, the ISCs can provide users with personalised interaction experiences which might lead to a sense of belonging and understanding.

4.6 Selective Memory

As discussed previously, forgetting is important to prevent stale information from interfering with fresh information [2]. Most humans routinely forget details of their experiences [36] although the real reason for this – whether it is due to actual loss of information or inability to retrieve it – is unclear. In a way, memory reconstruction is a type of forgetting where we constantly update our knowledge and experiences with new incoming information. By designing memory model that incorporate forgetting, we can keep the size of memory under control and more scalable to long-term interaction tasks. This will lead to improved performance due to the decrease in the amount of information that needs to be processed. It will also allow the ISCs to focus on relevant and important information. In the reviewed work, only simple forgetting mechanisms are implemented, many interesting mechanisms such as interference and reconstruction process are yet to be explored.

4.7 Emotion- and Mood-based Retrieval

Up-to-date, almost no artificial intelligence research is focused directly on emotional recollection for intelligent agents apart from those listed in Section 3.3. Although the previously discussed work incorporate episodic and autobiographic memory for life stories narration, no real recollective experience is involved. From a human perspective, this might seem unnatural because there is a mismatch between the agent's discourse and behaviour or expression. If we want the viewers to understand that the agent's behaviour is driven by its internal state, we will need a mechanism to express it [92] because plausible and consistent behaviour is important for an impression of personality [70]. Humans are naturally talented in communication. Even without using natural language, we are able to express what we want to convey by showing appropriate gestures and facial expressions. In contrast, it is very difficult to achieve the same effect in virtual agents leading to the problem of behavioural incoherence [87]. Without a proper way of expression, human observers will not understand why agents behave in the way they did.

Research has shown that inconsistent displays of emotions can result in an agent being perceived negatively [28]. Therefore, it is very important for the memory model of ISCs to support emotion-based retrieval so that the agents can exhibit appropriate emotions while narrating their life stories. Memory retrieval based on mood congruency is another interesting direction to explore. Since we usually retrieve memories that are directly consistent with our current mood, it could be possible that an ISC that tells stories based on its active emotions will be perceived as more realistic and believable.

4.8 Knowledge Extension

One of the common problems that emerges as interaction time increases between ISCs and users is the lack of knowledge in the agents which usually leads to unintelligent and repetitive responses. This rapidly kills the motivation in users to continue the interaction. This issue could be easily addressed by giving ISCs larger memories of experiences and knowledge but it will require manual and tedious configuration. Moreover, it has restricted flexibility and does not scale up easily. One potential solution would be to exploit existing knowledge bases and ontologies from the realm of the semantic web from which ISCs can easily extract necessary information as the interactions demand. These knowledge bases can also be utilised to perform inferences under novel situations enabling ISCs to be more efficient in solving problems without external intervention.

5 Conclusion

Intelligent Social Companions should have the capability to remember, reconstruct and forget information perceived from their interaction environment so that they can update and adapt their memory accordingly. A ‘human-like’ memory in these companions will make them appear more plausible, natural and believable. It will help them to comprehend their world and act reliably, learn context- and socially appropriate behaviour, focus their attention on important information relevant to the current interaction situation, make predictions about potential actions, learn from experiences and avoid repetitive behaviour. It will also give them a sense of ‘self-identity’, important for social recognition. Moreover, affective-based memory retrieval based on emotions and mood will improve the companions’ social responsiveness through exhibition of appropriate expressions relevant to interaction and narrative contexts.

Of course, to create a real Intelligent Social Companion, progress is required not only in terms of memory modelling but in many areas ranging from low level perception and sensing capabilities to high level interaction capabilities such as expressive behaviour, interaction styles, reasoning, speech, conversational skills, long term responsiveness to affective states and so on. Only through meeting human cognitive and social needs will these companions appear familiar and natural to humans and subsequently be accepted into humans’ daily life.

Acknowledgements

This work was partially supported by the European Commission (EC) and is currently funded by the EU FP7 ICT-215554 project LIREC (Living with Robots and Interactive Companions). The author is solely responsible for the content of this publication. It does not represent the opinion of the EC, and the EC is not responsible for any use that might be made of data appearing therein.

References

1. Alba, J.W., Hasher, L.: Is memory schematic? Psychological Bulletin **93**, 203–231 (1983)
2. Altmann, E.M., Gray, W.D.: Managing attention by preparing to forget. Human Factors and Ergonomics Society Annual Meeting Proceedings, Cognitive Ergonomics **1**(4), 152–155 (2000)
3. Anderson, J.R.: A spreading activation theory of memory. Journal of Verbal Learning and Verbal Behavior **22** (1983)
4. Atkinson, R., Shiffrin, R.: Human memory: A proposed system and its control processes. The Psychology of learning and motivation: Advances in Research and Theory **2** (1968)
5. Baddeley, A.D.: Is working memory still working? European Psychologist **7**(2), 8597 (2002)
6. Baddeley, A.D.: The psychology of memory. In: A.D. Baddeley, K.M. D., W.B. A. (eds.) The Essential Handbook of Memory Disorders for Clinicians. John Wiley & Sons, Ltd. (2004)

7. Baddeley, A.D., Hitch, G.J.: Working memory. Recent Advances in Learning and Motivation **8**, 47–89 (1974)
8. Barlett, F.C.: Remembering: A Study in Experimental and Social Psychology. Cambridge University Press, Cambridge, Great Britain (1932)
9. Benyon, D., Mival, O.: Landscaping personification technologies: from interactions to relationships. In: CHI '08 extended abstracts on Human factors in computing systems, pp. 3657–3662. ACM (2008)
10. Bickmore, T.W., Schulman, D.: A virtual laboratory for studying long-term relationships between humans and virtual agents. In: AAMAS2009, pp. 297–304. Budapest (2009)
11. Bickmore, T.W., Schulman, D., Yin, L.: Engagement vs. deceit: Virtual humans with human autobiographies. In: Proceedings of The 9th International Conference on Intelligent Virtual Agents, pp. 6–19. Springer, Amsterdam (2009)
12. Bluck, S.: Autobiographical memory: Exploring its functions in everyday life. Memory **11**(2), 113–123 (2003)
13. Bluck, S., Alea, N., Habermas, T., Rubin, D.C.: A tale of three functions: The self-reported uses of autobiographical memory. Social Cognition **23**(1), 91–117 (2005)
14. Bouton, M.E., Nelson, J.B., Rosas, J.M.: Stimulus generalization, context change, and forgetting. Psychological Bulletin **125**, 171–186 (2008)
15. Bradley, J., Mival, O., Benyon, D.: Wizard of oz experiments for companions. In: Proceedings of the 2009 British Computer Society Conference on Human-Computer Interaction, pp. 313–317. British Computer Society, Swinton, UK (2009)
16. Bradshaw, G.L., Anderson, J.R.: Elaborative encoding as an explanation of levels of processing. Journal of Verbal Learning and Verbal Behavior **21**, 165–174 (1982)
17. Bransky, K., Richards, D.: Investigating the role of memory in interactions between intelligent virtual characters and humans over time. In: Proceedings of International Workshop on Interacting with ECAs as Virtual Characters, AAMAS 2010. Toronto Canada (2010)
18. Brom, C., Lukavský, J.: Towards virtual characters with episodic memory ii: Episodic memory strikes back. In: Proceeding of Empathic Agents, AAMAS Workshop. Budapest (2009)
19. Brown, J.: Some tests of the decay theory of immediate memory. Quarterly Journal of Experimental Psychology **10**, 12–21 (1958)
20. Bruner, J.: The narrative construction of reality. Critical Inquiry **18**(1), 121 (1991)
21. Burkert, O., Brom, C., Kadlec, R., Lukavský, J.: Timing in episodic memory: Virtual characters in action. In: M.Y. Lim, W.C. Ho (eds.) Proceeding of the Remembering Who We Are - Humam Memory for Aritificial Agents Symposium, AISB Covention, pp. 1–9. Leicester, UK (2010)
22. de Campos, J.C.F.: May: my memories are yours an interactive companion that saves the user's memories (2010). MSc Thesis
23. Carver, J.M.: Emotional memory management: Positive control over your memory. Burn Survivors Throughout the World Inc. (2005). Http://www.burnsurvivorsttw.org/articles/memory.html
24. Chang, S.J., Lee, I.H.: An emotion model using emotional memory and consciousness occupancy ratio. In: Proceedings of the 2005 international conference on Augmented tele-existence, ICAT '05, pp. 272–272. ACM, New York, NY, USA (2005)
25. Conde, T., Thalmann, D.: Autonomous virtual agents learning a cognitive model and evolving. In: T. Panayiotopoulous, J. Gratch, R. Aylett, D. Ballin, P. Olivier, T. Rist (eds.) Proceedings of The 5th International Working Conference on Intelligent Virtual Agents, pp. 88–98. Kos, Greece (2005)
26. Conway, M.A.: Sensory-perceptual episodic memory and its context: autobiographical memory. Philosophical Transactions of the Royal Society: Biological Sciences **356**, 1375–1384 (2001)
27. Craik, F.I.M., Lockhart, R.S.: Levels of processing: A framework for memory research. Journal of Verbal Learning and Verbal Behavior **11**, 671–684 (1972)
28. Creed, C., Beale, R.: Psychological responses to simulated displays of mismatched emotional expressions. Interacting with Computers **20**(2), 225–239 (2008)

29. Dautenhahn, K.: Story-telling in virtual environments. In: Working Notes: Intelligent Virtual Environments, Workshop at the 13th Biennial European Conference on Aritificial Intelligence. Brighton, UK (1998)
30. De Zeeuw, C.I.: Time and tide in cerebellar memory formation. Current Opinion on Neurobiology **15**, 667–674 (2005)
31. Dias, J., Ho, W.C., Vogt, T., Beeckman, N., Paiva, A., André, E.: I know what i did last summer: Autobiographic memory in synthetic characters. In: Affective Computing and Intelligent Interaction, pp. 606–617. Springer (2007)
32. Dias, J., Paiva, A.: Feeling and reasoning: A computational model for emotional agents. In: 12th Portuguese Conference on Artificial Intelligence (EPIA 2005), pp. 127–140. Springer, Portugal (2005)
33. Dodd, W.: The design of procedural, semantic and episodic memory systems for a cognitive robot. Ph.D. thesis, Vanderbilt University (2005)
34. Doherty, I., O'Riordan, C.: Toward more humanlike npcs for first-/third-person shooter games. AI Game Programming Wisdom IV pp. 499 – 512 (2008)
35. Dreyfuss, H.: Liking and Loving An Invitation to Social Psychology. Holt, Rinehart and Winston, New York (1973)
36. Ebbinghaus, H.: Memory: A Contribution to Experimental Psychology. New York: Teachers College, Columbia University (1885/1913)
37. Enz, S., Diruf, M., Spielhagen, C., C., Z., , Vargas, P.A.: The social role of robots in the future explorative measurement of hopes and fears. International Journal of Social Robotics Under review
38. Festinger, L.: A Theory of Cognitive Dissonance. Stanford University Press, Stanford, CA (1957)
39. Fiske, S.T.: Social Beings: Core Motives in Social Psychology. Wiley, New York (2004)
40. Forgas, J.P.: Mood and judgment: The affect infusion model (aim). Psychological Bulletin **117**(1), 39–66 (1995)
41. Francis Jr., A.G., Mehta, M., Ram, A.: Emotional memory and adaptive personalities. In: J. Vallverdú, D. Casacuberta (eds.) Handbook of Research on Synthetic Emotions and Sociable Robotics: New Applications in Affective Computing and Artificial Intelligence. IGI Global., Hershey, Pennsylvania (2000). To appear
42. Freud, A.: The Ego and the Mechanisms of Defence. Hogarth Press and Institute of Psycho-Analysis, London (1937)
43. Frijda, N.H., Mesquita, B.: Beliefs through emotions. In: N.H. Frijda, A.S.R. Manstead, S. Bem (eds.) Emotions and Beliefs, pp. 45–77. Cambridge University Press, Cambridge, UK (2000)
44. Gold, P.E.: A proposed neurobiological basis for regulating memory storage for significant events. Affect and Accuracy in Recall: Studies of 'Flashbulb' Memories pp. 141–161 (1992)
45. Gomes, P.M.F.: Meemos: Believable agents with episodic memory retrieval (2010). MSc Thesis
46. Halpern, S.: Forgetting is the new normal. Adapted from Can't Remember What I Forgot: The Good News from the Front Lines of Memory **9**, 36–39 (2008)
47. Harmon-Jones, E.: A cognitive dissonance theory perspective on the role of emotion in the maintenance and change of beliefs and attitudes. In: N.H. Frijda, A.S.R. Manstead, S. Bem (eds.) Emotions and Beliefs, pp. 185–211. Cambridge University Press, Cambridge, UK (2000)
48. Hayes-Roth, B.: A blackboard architecture for control. Artificial Intelligence **26**(3), 251–321 (1985)
49. Ho, W.C.: Computational memory architectures for autobiographic and narrative virtual agents. Ph.D. thesis, University of Hertfordshire (2005)
50. Ho, W.C., Dautenhahn, K.: Towards a narrative mind: Creating coherent life stories for believable agents. In: Proceeding of the 8th International Conference on Intelligent Virtual Agent, pp. 59–72. Springer-Verlag (2008)

51. Ho, W.C., Dautenhahn, K., Nehaniv, C.L.: Comparing different control architectures for autobiographic agents in static virtual environments. In: Proceeding of Intelligent Virtual Agents Conference 2003, pp. 182–191 (2003)
52. Ho, W.C., Lim, M.Y., Vargas, P.A., Enz, S., Dautenhahn, K., Aylett, R.: An initial memory model for virtual and robot companions supporting migration and long-term interaction. In: ROMAN 2009, IEEE International Symposium on Robot and Human Interactive Communication, pp. 277–284. Tokyo (2009)
53. Hymann, I.E.: Conversational remembering: Story recall with a peer versus for an experimenter. Applied Cognitive Psychologyn **8**(1), 49–66 (1994)
54. K., O., Morris, R., Shadbolt, N., Hitch, G.J., Hall, W., Beagrie, N.: Memories for life: a review of the science and technology. Journal of The Royal Society Interface **3**, 351–365 (2006)
55. Kopp, S., Gesellensetter, L., Krämer, N.C., Wachsmuth, I.: A conversational agent as museum guide - design and evaluation of a real-world application. In: Intelligent Virtual Agents Conference, pp. 329–343. Springer-Verlag, Greece (2005)
56. Kramer, J., Noronha, S., Vergo, J.: A user-centered design approach to personalization. Communication of the ACM **43**(8), 44–48 (2000)
57. LeDoux, J.: The Emotional Brain: The Mysterious Underpinnings of Emotional Life, london edn. Phoenix, Orion Books Ltd. (1999)
58. Levenson, J.M.: Epigenetic mechanisms: a common theme in vertebrate and invertebrate memory formation. Cellular and Molecular Life Sciences **63**, 1009–1016 (2006)
59. Levine, L.J.: Reconstructing memory for emotions. Journal of Experimental Psychology: General **126**(2), 165–177 (1997)
60. Lim, M.Y.: Emotions, behaviour and belief regulation in an intelligent guide with attitude. Ph.D. thesis, School of Mathematical and Computer Sciences, Heriot-Watt University, Edinburgh, UK (2007)
61. Lim, M.Y., Aylett, R., Ho, W.C., Vargas, P., Enz, S.: A socially-aware memory for companion agents. In: Proceedings of The 9th International Conference on Intelligent Virtual Agents, pp. 51–62. Springer, Amsterdam (2009)
62. Lim, M.Y., Ho, W.C., Aylett, R.: Spreading activation - an autobiographic memory retrieval mechanism for social companions. In: Proceedings of The 10th International Conference on Intelligent Virtual Agents. Philadelphia (2010)
63. Lim, M.Y., Kriegel, M., Aylett, R., Deshmukh, A.: Sarah: An eca in the wild. In: Workshop on Interacting with ECAs as Virtual Characters. Toronto (2010)
64. Linde, C.: Life Stories: The Creation of Coherence. Oxford University Press (1993)
65. Mavridis, N., Petychakis, M.: Human-like memory systems for interactive robots: Desiderata and two case studies utilising grounded situation models and online social networking. In: M.Y. Lim, W.C. Ho (eds.) Proceeding of the Remembering Who We Are - Humam Memory for Aritificial Agents Symposium, AISB Covention, pp. 46–51. Leicester, UK (2010)
66. McCallum, A.R.: Instance-based state identification for reinforcement learning. In: D.D. Frank Detje, H. Schaub (eds.) Advances in Neural Information Processing Systems, NIPS 7 (1995)
67. McNamara, T.P., A., D.V.: The context of memory retrieval. Journal of Memory and Language **35**, 877–892 (1996)
68. Miller, G.A.: The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychological Review **63**, 81–97 (1956)
69. Minsky, M.: Society of Mind. Simon and Schuster (1988)
70. Moffat, D.: Personality parameters and programs. In: P. Petta, R. Trappl (eds.) Creating Personalities for Synthetic Actors, Towards Autonomous Personality Agents, pp. 120–165. Springer-Verlag (1997)
71. Mori, M.: Bukimi no tani (translated by k. f. macdorman and t. minato). Energy **7**(4), 33–35 (1970)
72. Nass, C., Moon, Y.: Machines and mindlessness: Social responses to computers. Journal of Social Issues **65**(1), 81–103 (2000)

73. Nelson, K.: The psychological and social origins of autobiographical memory. Psychological Science **4**, 345–349 (1993)
74. Nelson, K.: Self and social functions: Individual autobiographical memory and collective narrative. Memory **11**(2), 125–136 (2003)
75. Newell, A.: Unified Theories of Cognition. Harvard University Press, Cambridge, Mass. (1990)
76. Nuxoll, A., Laird, J.: A cognitive model of episodic memory integrated with a general cognitive architecture. In: International Conference on Cognitive Modeling (204)
77. Nuxoll, A., Tecuci, D., Ho, W.C., Wang, N.: Comparing forgetting algorithms for artificial episodic memory systems. In: M.Y. Lim, W.C. Ho (eds.) Proceeding of the Remembering Who We Are - Humam Memory for Aritificial Agents Symposium, AISB Covention. Leicester, UK (2010)
78. Nuxoll, A.M.: Enhancing intelligent agents with episodic memory. Ph.D. thesis, The University of Michigan (2007)
79. Ogino, M., Ooide, T., Watanabe, A., Asada, M.: Acquiring peekaboo communication: Early communication model based on reward prediction. In: Proceedings of IEEE International Conference in Development and Learning. London, UK (2007)
80. Picard, R.W.: Affective Computing. MIT Press (1997)
81. Richter-Levin, G., Akirav, I.: Emotional tagging of memory formation - in the search for neural mechanisms. Brain Research Reviews **43**, 247–256 (2003)
82. Riesberg, D., Heuer, F.: Remembering the details of emotional events. Affect and Accuracy in Recall: Studies of 'Flashbulb' Memories pp. 162–190 (1992)
83. Robinson, M.D., Clore, G.L.: Episodic and semantic knowledge in emotional self-report: Evidence for two judgment processes. Journal of Personality and Social Psychology **83**, 198–215 (2002)
84. Schacter, D.L.: Implicit memory: history and current status. Journal of Experimental Psychology: Learning, Memory, and Cognition **13**, 501–518 (1987)
85. Schank, R.C.: Dynamic memory: A theory of reminding and learning in computers and people. Cambridge University Press, United States (1982)
86. Schank, R.C., Abelson, R.: Knowledge and memory: The real story. In: J. Robert S. Wyer (ed.) Knowledge and Memory: The Real Story, pp. 1–85. Lawrence Erlbaum Associates, Hilldale, NJ (1995)
87. Sengers, P.: Narrative and schizophrenia in artificial agents. In: M. Mateas, P. Sengers (eds.) Narrative Intelligence, p. 259278. Amsterdam: John Benjamins (2003)
88. Sparrow, R.: Killer robots. Journal of Applied Science **24**(1) (2006)
89. Squire, L.R.: Declarative and non-declarative memory: multiple brain systems supporting learning and memory. Journal of Cognitive Neuroscience **4**, 232–243 (1992)
90. Syrdal, D.S., Walters, M.L., Otero, N., Koay, K.L., Dautenhahn, K.: He knows when you are sleeping - privacy and the personal robot companion. Tech. rep. (2007)
91. Tecuci, D.G.: A generic memory module for events. Ph.D. thesis, The University of Texas at Austin (2007)
92. Thomas, F., Johnston, O.: Disney Animation: The Illusion of Life. New York: Abbevile Press (1981)
93. Tulving, E.: What is episodic memory? Current Directions in Psychological Science **2**, 67–70 (1993)
94. Tulving, E.: Episodic memory: From mind to brain. Annual Review of Psychology **53**(1), 1–25 (2002)
95. Tulving, E., Psotka, J.: Retroactive inhibition in free recall: inaccessibility of information available in the memory stores. Journal of Experimental Psychology **87**, 116–124 (1971)
96. Vargas, P.A., Ho, W.C., Lim, M.Y., Enz, S., Fernaeus, Y., Aylett, R.: To forget or not to forget:towards a roboethical memory control. In: Killer Robots or Friendly Fridges: the Social Understanding of Artificial Intelligence, AISB'09, pp. 18–23. Edinburgh (2009)
97. Vere, S., Bickmore, T.: A basic agent. Computational Intelligence **6**, 41–60 (1990)
98. Veruggio, G.: The birth of roboethics. In: ICRA 2005, IEEE International Conference on Robotics and Automation Workshop on Robo-Ethics (2005)

99. Veruggio, G., Operto, F.: Roboethics: A bottom-up interdisciplinary discourse in the field of applied ethics in robotics. International Review of Information Ethics **6**, 3–8 (2006)
100. Wilks, Y.: Foreword. In: Y. Wilks (ed.) Close Engagements with Artificial Companions Key social, psychological, ethical and design issues, pp. 4–6. John Benjamin Publishing Company (2010)