To Forget or Not to Forget: Towards a Roboethical Memory Control

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Abstract. A long-term human robot interaction (HRI), which involves data storage of personal information, naturally raises ethical issues as a primary concern. This paper is an attempt to rise to this challenge by speculating how to best build and control a "roboethical" memory for a robot companion. We believe that memory is an essential feature in the design of a robot mind for this kind of long-term HRI. Hence, this work tries to create a link between "human-like" memory modelling and the new Roboethics discipline. We embark on this endeavour by proposing forgetting mechanisms that would dictate what the robot companion should and should not forget in addition to suggesting a primary experiment to test the memory prototype.

1 INTRODUCTION

Recently there has been an increasing interest in establishing the scientific basis for developing artificial companions that users will want to interact with over a long period of time in their own social settings [28] [29] [31]. An artificial companion could be a robot, but could also be an intelligent graphical character on a mobile handheld device, a children's toy or, given mobility (i.e. ability to migrate) between such devices and platforms, a combination of all of these.

A frequently asked research question arises from this fascinating research goal: How do we create a new computer technology that supports long-term relationships between humans and artificial companions? Moreover, what technologies would be essential for the design of the artificial companion?

From a technical perspective, interaction mechanisms, long-term responsiveness to human affective states, interfaces, memory, data security and privacy are some of the areas, which must be investigated in order to develop long-life personalized artificial companions. Amongst the aforementioned areas, memory modelling can be considered as an essential aspect in any project relating to the long-term social relationship between a human and an artificial companion.

We argue that the inclusion of "human-like" memory in artificial companions will enable them to behave in more natural and believable ways. The existence of this memory will help the artificial companions to comprehend their world by adapting to new circumstances. It will allow them to make predictions about a situation and thus produce appropriate behaviours. In other words, their past experiences will serve as guidelines for their future actions. Applying these guidelines, the artificial companion will be able to act in certain consistent ways and thus exhibit a "personality" - a reflection of the "self" that is important in social communication [15].

Moreover, apart from the intrinsic complexity faced by scientists when modelling a human-like memory, we envisage that there are some additional challenges in attempting to devise a memory for the artificial companion. For instance, how to incorporate emotional aspects? What in the information the companion has perceived while interacting with the user or the environment should it forget and what not forget? In addition to other ethical issues might possibly be involved?

This paper seeks to provide a broader definition of human memory focusing on forgetting mechanisms while trying to highlight in which ways a long-term companion memory is linked with privacy and thus ethical issues. For the sake of argument, in this paper we will centre our ethics discussion only on robots as role models for our artificial companions.

The remaining of this work is organised as follows: Section 2 will define human memory and forgetting according to literature from Psychology and Cognitive Science. In Section 3, we will give an overview of ethical issues and introduce the new discipline named Roboethics. Section 4 will consider the nature of the link between a robot's artificial memory and Roboethics, in addition to proposing ways of controlling the memory of a robot companion. Section 5 proposes a first experiment and Section 6 will present some conclusions and describe future work.

2 MEMORY AND FORGETTING

"*You have to begin to lose your memory, if only in bits and pieces, to realize that memory is what makes our lives. Life without memory is no life at all, just as intelligence without the possibility of expression is not really intelligence. Our memory is our coherence, our reason, our feeling, even our action. Without it, we are nothing*". - Luis Buuel. Spanish director, 1900-1983.

Life is full of stories: stories we remember through experiences, stories we heard and stories we compose. These stories are a reflection of the "self" when they are told and without them, life is meaningless. An individual without past stories will not be able to appreciate life, share their experiences with others or make sense of anything happening around them. This is due to the fact that "understanding the world means explaining what has happened in it in a way that seems consonant with what you already believe" [32]. Memories are part of what makes up our personality, controls our behaviours and often influences our mood [12].

According to Le Doux [26], our brain contains a variety of different memory systems that work in parallel to give rise to indepen-

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dent memory functions. Conscious, declarative or explicit memories are mediated by the hippocampus and related cortical areas, whereas implicit emotional memory involves the amygdala and related areas [23]. 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.

In general, memory works on the basis of three different processes: first, information from the sensory system of the organism (external and internal sensors) is encoded, then stored, and finally retrieved (if not forgotten). It is as yet unclear and controversial among scientists, how exactly memory works [41] [16] [27].

Computationally, memory is modelled as a succession of three different stores, one for the sensory information, the second for short-term memory (STM), and the last for long-term memory (LTM); the above described processes, encoding, storing, and retrieving, work on these three entities.

In the store for sensory information, incoming perceptual input from the sensors is either ignored or attended to. In the case that it is ignored, it is removed after a split second. In the case that one attends to it, it survives, writes over "old" sensory input information, and is processed in order to assess its meaning. Once the meaning is assessed, the information is encoded and transferred to the short-term memory. Information that enters this memory can be lost or forgotten.

Long-term memory keeps a large quantity of information for potentially a very long time. Information stored there can be of very different types. While researching into human memory, one faces some serious problems. First, the quality of memory retrieval can only be measured by comparing the consistency of different retrievals at different points of time (indirect measurement). Thus, even if people can elaborate not only on an (emotional) event but also on situational context information surrounding the event, we do not really know whether the retrieved information is accurate [13] [42]. There are some solutions to this problem; for instance, the simulation of events in the laboratory and the direct assessment of memories of these.

However, in the context of memories that have been stored based on real-life events and experiences, the American Psychological Association comes to the conclusion that "at this point it is impossible, without other corroborative evidence, to distinguish a true memory from a false one".

Summing up, the three main activities related to memory modelling are: encoding, remembering [8] and forgetting. Information from short-term memory (STM) is encoded in long-term memory (LTM) through repeated exposure and generalisation. Remembering or retrieval involves recall and recognition while forgetting may be caused by several processes.

In this sense, an artificial companion should have the capability to "remember" and "forget" information perceived from its interaction environment so that it can update and adapt its memory accordingly. By constantly reconstructing memory, e.g. using remembering and forgetting mechanisms, the artificial companion will be able to learn to behave in an appropriate way because its attention can be focused on important information relevant to the current interaction situation.

If we were to record every bit of incoming information, we would have information overloaded, difficulty in organizing the information and difficulty in focusing on one piece of information at a time. Therefore, forgetting is essential and useful, thus a number of theories of forgetting have been developed by neuroscientists and psychologists, which aim at explaining these mechanisms, and thus why we forget. These theories can be split into two groups. One is mostly associated with forgetting from STM and another one is with forgetting from LTM, as follows:

- STM

a) Trace decay

This theory suggests that memory fades away with time and leaves a trace in the brain in the form of physical and/or chemical change in the nervous system. This trace would then be subjected to an automatic fade or decay over time [11].

b) Displacement

This theory explains forgetting as due to lack of availability or limited capacity of the STM. In this way, new information "displaces" old information when STM is "full".

- LTM

a) Interference

For this theory, LTM can be disrupted or interfered with by other memories, i.e. memories interfere with one another retroactively or proactively [7] [6]. Retroactive interference means that information that is encoded later interferes with information that is encoded at an earlier stage; while proactive interference means that information that is encoded at an earlier stage interferes with information that is encoded at a later stage (e.g. witnesses in court).

b) Lack of consolidation

This theory states that a certain amount of time is necessary for some alteration of the brain substrate to become permanent, i.e. the consolidation process. Therefore, impairment on the consolidation process, such as damage to the hippocampus or aging, may thus cause forgetting [43].

c) Retrieval failure

The retrieval failure is characterized when information stored in the LTM cannot be accessed [36]. When it comes to retrieving information from memory, contextual cues are crucial. Tulving and Psotka [37] have shown that forgetting is due to the absence of a valid cue for recall (cued recall) and that recalling memories fails if contextual information is missing. As Bouton and collaborators [9] put it: "Retrieval is best when there is a match between the conditions present during encoding and the conditions present during retrieval. The passage of time can create a mismatch because internal and external contextual cues that were present during learning may change or fluctuate over time. Thus, the passage of may change the background context and make it less likely that target material will be retrieved".

d) Repression

Repression occurs when memories are unconsciously blocked from our awareness. It could be seen as the purposeful but subconscious block of memories. These strategies to "forget" disturbing experiences have been researched in psychoanalysis as defence mechanisms, strategies that serve to protect the self from situations and emotions with which one cannot cope [18]. In case of these unconscious or conscious strategies of motivated forgetting, remembering, discussing or rehearsing memories are important techniques to strengthen the retrieval of the suppressed or repressed memories. Similarly, forgetting details of disturbing events might also be due to the fact that disturbing events are simply less often discussed and rehearsed than positive memories.

Apart form the aforementioned theories, forgetting has also been linked to sleep, distress, exercise and diet. The research into the influence of sleeping on memory and forgetting can be subsumed with the finding that it is the metabolic processes that take place during sleeping that influence forgetting (e.g. [19]). Results focusing on the absence of sleep on memory and forgetting can be interpreted as being at least partly the consequence of heightened stress levels that are a direct result of the absence of sleep. As far as stress level and memory

is concerned, extensively high cortisol levels that result from dangerous situations and have the function to prepare the organism for fight or attack, damage brain cells if they are not controlled. Normally, internal regulative mechanisms stop the distribution of cortisol within a short time frame, but this control mechanism can be impaired, e.g. in depressive patients.

In the next section, we will provide an overview of ethics issues incurred on social relationships and introduce the new discipline named Roboethics.

3 ETHICS TO DEFINE ROBOETHICS

In discussing ethics, we will first describe the main theories related to ethical behaviour on social relationships in general. Then, we will concentrate on the ethics related to human robot interaction (HRI). Therefore, we will focus on robots as long-term companions, including the implications of their memory modelling with regard to privacy issues such as data security and data disclosure.

There are three types of theory that try to encompass ethical concerns: consequentialist, deontological and virtue-based. The former states that the consequences should rule one's actions. In this sense, an ethical behaviour should involve the ability to predict the result of an action, in addition to evaluating the results of an action according to positive expectations and/or desires.

In deontological theory, an action is evaluated a priori as being moral or immoral irrespective of its consequences. Usually, a set of moral rules are created describing a deontological moral system. A number of such systems have been created [20]. Nonetheless, conflicts may always arise when dealing with a rule-based system and thus one must know how to solve the upcoming dilemmas.

Virtue-based theory, on the other hand, considers one's character in terms of "being" not "doing". Hence, ethics is a question of character and learning by practicing is more relevant than theory.

As previously stated, we are concern about the ethics involved in the design and use of robot technology in everyday settings from a user-oriented perspective. This requires a balanced discussion that may not begin with life and death [5] [14] [3], but on a more general level grounded in real culture. Relevant questions then concern how the technology that we build affects existing social practices, how the image of robots in popular media affects us and our designs, and the values that people in general associate with robotic technology.

One should not underestimate the fact that the development of robotic technology involves systems that are extremely complex and in a way probably unpredictable given it depends on how such machines are created. Notwithstanding the distress that might be incurred, we believe that there is no need to be alarmist [24]. Of course, history has given us enough reasons to become concerned with the uncontrolled development of new technology e.g., war built-purpose robots [4] and hence, ethical issues involved should undoubtedly be part of our present concerns.

With the aim of devising a human-centred ethics, which would involve long-term ethical concerns whilst developing robotic technology, a new discipline named Roboethics was created [38] [39]. Its prime objective is to provide scientific, cultural and technical tools that can be shared by different social groups and beliefs. Thus, it is believed that Roboethics should not only comply with the widely accepted "Charts of Human Rights" but also consider ethical theories as described earlier in this section. Moreover, Veruggio [38] enquires whether Roboethics is a problem for the individual scientist, for the end user, or for the concerned person to deal with, in her/his own consciousness, or whether it is a social problem to be addressed at an institutional level. We advocate that it should be a combination of all of these, given that conscious individual scientists should lead to a conscious institution and thus to an ethical end-product to the end-user.

Roboethics should analyse the effects of robotics such as abrogation of responsibilities, lack of access, deliberate abuse, terrorism and privacy amongst others, in many application fields, such as economy, society, law, elderly, health and childcare. However, in this work, we concentrate on the ethics related to long-term HRI, focusing more on data security and thus privacy issues.

In the next section we will describe related work which has already approached ethical issues on robotics, memory models and experiments, focusing on which content should be forgotten by the robot, while trying to investigate a hypothesis on how to control the robot's memory.

4 TOWARDS A ROBOETHICAL MEMORY CONTROL

So far, the idea of a robot companion has not been widely accepted and sometimes not even considered or imagined. There are also some scientists and philosophers who clearly stand against its use in all circumstances. Take Sparrow for instance [33] [34]. He argues that while we are unable to create robots with real personality, we could make the mistake of viewing our creations for what they are not and hence, this could involve a potential ethical danger [2].

Syrdal and collaborators [35] addressed the relevance of considering privacy as an ethical problem on HRI as pointed out at the EURON Roboethics Roadmap [39]. The authors conducted an exploration experiment using a human-sized robot, which was operated under remote control while interacting with 12 participants in a long-term trial i.e., "The Wizard of Oz Method" [25]. One important aspect raised by the analysis of the results was that of the influence of nationality and thus cultural differences between the participants.

As expected, people were mostly concerned with "what" was being stored on the memory of the robot companion and "how" this data would be processed and to "whom" this information would be further disclosed. All things considered, it was concluded that not only systems that are meant to be used by general public should strive to explicitly justify any data captured from its users but also that privacy and data protection remain an important field of research.

In our research we focus on what the artificial companion should and should not forget and its consequences when taking into consideration ethical concerns. For Gips [21], each ethical theory presented on Section 3, has its pros and cons and thus he poses a question that is concerned with "What types of ethical theories can be used as the basis for programs for ethical robots?" For instance, the consequentialist theory would be the easiest to implement in a robot but prediction would be an issue. The deontological theory might also seem straightforward to implement but arising conflicting obligations would be pre-emptive. The virtue-based theory seems to resonate partially with the evolutionary robotics approach but the unpredictability might become undesired. We believe that in order to create an ethical robot one should consider incorporating aspects of all ethical theories [40].

In our point of view the three theories could be combined in a way of creating a master "roboethical" theory, which would encompass all positive features of each one, while attempting to overcome the shortfalls. For instance, an ethical robot's mind could be programmed as a set of rules (deontological theory), which could be learned by practice (virtue-based theory) and also by applying evolution and predic-

tion (consequentialist theory). Of course when we mention the robots mind, we are mostly interested in the robots memory modelling and the related forgetting mechanisms, which is the focus of this investigation.

Forgetting is useful to improve efficiency, scalability and adaptability of cognitive systems operating in dynamic task environments, such as a robot's interaction environments. Forgetting could be viewed as a way of controlling the memory of the robot companion for it could be used to regulate [22] the type and amount of data stored on the robots memory, giving rise to a more reliable artificial companion, in data security and privacy terms.

Towards this roboethical memory control, a robot companion can learn (virtue-based) data privacy regarding contents as well as contexts from making mistakes that is later rectified by the user. Each time a robot makes a mistake by retrieving a piece of personally sensitive data and the user corrects the robot, the memory architecture should create a new rule (deontological) to handle the same type of data under the remembered context, namely the current environment and other people's presence. Once the new rule is reinforced by the user, it allows the robot to be attentive to a particular type of information while interacting with the environment and perceiving data through sensors. This new rule can help processing the information and enable a "situational forgetting" mechanism, which allows the robot to "forget" a piece of sensitive information under specific circumstances to satisfy the user's expectations and attend its requests via making accurate predictions (consequentialist).

In order to implement such control, our proposed memory model should include forgetting mechanisms by not only utilizing the trace or functional decay theory [11] [1] for STM and LTM but also considering displacement, interference, consolidation and most important repression. A repression mechanism could be implemented in order to allow the user to "repress" any memory event that might be considered inadequate for storage. Following these guidelines, a robot's memory can be personally tailored to suit particular user needs while initialising the robot. The same memory architecture, with different levels of forgetting and repression mechanisms to handle sensitive contents, can support various user groups with regards to personal privacy. For instance, a robot companion working in an office can be personalised to remind workers their schedule, meeting appointment and regular break times; however this robot should avoid remembering workers' personal information such as someone's home address or salary, because these are sensitive issues to individuals in the office environment. In contrast, a robot companion living with the user in the home environment can store more personal information at users' request. This robot can help the user with daily tasks at home and also remind the user the time to take medicine, appointments with a doctor or personal dates.

For the general memory model, basically, memory traces that are of the immediate past are denser than the old ones. When information is perceived, it enters the STM. With continuous activation through rehearsal or frequent recall this memory may eventually become LTM. However, if the information falls into disuse, the memory trace will start to decay and eventually fade from memory.

The information that receives frequent attention will go through reconstruction processes before it is consolidated as LTM. This is part of the learning process where memory structures are modified continuously based on incoming information to ensure their currency with respect to the world state. By being able to notice and recall differences in experiences, the robot will be able to learn about its environment more effectively. General structures will help the robot in deciding what to pay attention to, and "reminding" forces it to make use of prior knowledge to form expectations. Nonetheless, care needs to be taken when generalising information to ensure that particular differences that may be valuable are not lost.

To recapitulate, by considering ethical issues, a prior knowledge (a deontological system), a learning process (virtue-based) and a prediction scheme (consequentialist) should be part of the "roboethical" system as described earlier together with the aforementioned forgetting mechanisms. In this way, the user could control "what" is being stored, "how" it is being encoded and to "whom" it would be available.

5 PROPOSED PRIMARY EXPERIMENTS

Following Brom's et al. [10] previous work on characters with artificial memory, we suggest as a first experiment to test our memory model, the use of the ORIENT (Overcoming Refugee Integration with Empathic Novel Technology) software platform developed for the ECIRCUS project [30].

Although it has graphical characters acting as artificial companions (Figure 1) and not robots, we think it could provide a valuable test-bed for assessing ethical issues related to privacy and cultural differences. The ORIENT software platform tackled nationality issues where graphical characters were used to help diminishing prejudice against new cultures trying to educate the user to learn how to behave and thus respect other nationalities and cultural differences [30].

Furthermore, the ORIENT platform was build upon the FearNot! Affective Mind Architecture (FAtiMA) [17] which has an autobiographic memory model partially implemented allowing us to further improve and adapt the model to our purposes without having to start from scratch.

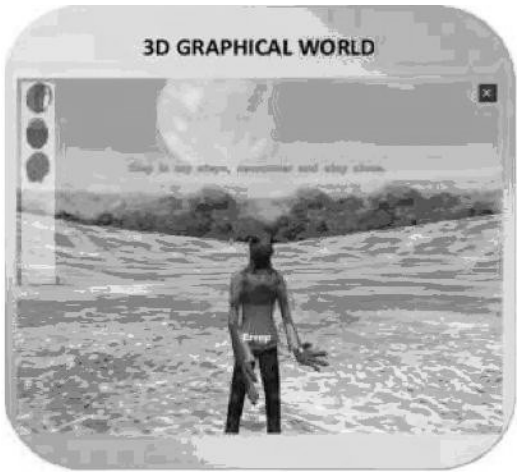

Figure 1. ORIENT system graphical interface showing part of a small planet called ORIENT, which is inhabited by an alien race, the Sprytes

We can picture a number of scenarios within the ORIENT platform where our case study could be conducted. For instance, by making use of the proposed remembering and forgetting mechanisms, the artificial companion could adapt itself to the user preferences in terms of cultural identity in a social event or on a daily basis activity.

Additionally, it could also learn to forget particular episodes if told so by the user or not to disclose any information shared in private.

Before designing the implementation module, it is imperative to further discuss whether the ORIENT artificial companion should also have its own culture or not? In ORIENT an individual (or Spryte) could have its own personality despite being immersed in a culture. Hence, we should identify the impact and relevance a cultural heritage could have on our study.

6 CONCLUSIONS and FUTURE WORK

This paper speculates on how to best build a memory model for a robot companion while being concerned with ethical issues involving data security and thus privacy aspects.

After discoursing about memory and forgetting, ethical theories related to the new Roboethics discipline were described.

The work discussed why a memory model should encompass ethical issues and a first case study was suggested as a test-bed for the hypothesis by checking whether the artificial companion can perceive, remember and react to human users.

In conclusion, one may ask: "Could a robot ever be ethical?" [21] [40]. We believe the answer is "yes" if one has clear ethical concerns and is conscious of how the robot is being developed and to what purpose. Particularly, bearing in mind that a robot should be a partner and co-exist with human beings while assisting them both physically and psychologically, in addition to contribute to the realization of a safe and peaceful society [38] [39].

Future work includes a formal detailed proposal of an initial memory model for an artificial companion taking into consideration all the ethical issues raised on this present work apart from further describing the first case study to test the memory prototype.

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REFERENCES

[1] E. M. Altmann and W. D. Gray, 'Managing attention by preparing to forget', *Human Factors and Ergonomics Society Annual Meeting Proceedings*, **1(4)**, 152–155, (2000).
[2] P. Ambo. Mechanical love. a film directed by Phie Ambo, http://www.danishdocumentary.com/store, 2007.
[3] S. Anderson, 'Asimov's 'three laws of robotics' and machine metaethics', *AI and Society*, **on line**, (2007).
[4] R. C. Arkin, 'Governing lethal behavior: embedding ethics in a hybrid deliberative/reactive robot architecture', *Proceedings of the 3rd ACM/IEEE international Conference on Human Robot interaction*, 152–155, (2008). DOI= http://doi.acm.org/10.1145/1349822.1349839.
[5] I. Asimov, *I, Robot*, Doubleday and Co., New York, 1950.
[6] A.D. Baddeley, *Human memory: Theory and Practice (Revised Edition)*, Psychology Press, Hove, 1997.
[7] A.D. Baddeley, *Essentials of Human Memory*, Psychology Press, Hove, 1999.
[8] F. C. Bartlett, *Remembering: A Study in Experimental and Social Psychology*, Cambridge University Press, Cambridge, Great Britain, 1932.
[9] Nelson J. B. Bouton, M. E. and J. M. Rosas, 'Stimulus generalization, context change, and forgetting', *Psychological Bulletin*, **125**, 171–186, (1999).
[10] Peskova K. Lukavskyz J. Brom, C., 'What does your actor remember? towards characters with a full episodic memory', *In Cavazza, M., Donikian, S., eds.: International Conference on Virtual Storytelling, Lecture Notes in Computer Science*, **4871**, 89–101, (2007).
[11] J. Brown, 'Some tests of the decay theory of immediate memory', *Q. J. Exp. Psychol.*, **10**, 12–21, (1958).
[12] J. M. Carver, 'Emotional memory management: Positive control over your memory', *Burn Survivors Throughout the World Inc.*, (2005). http://www.burnsurvivorsttw.org/articles/memory.html.
[13] S.-A. Christiansen and M. A. Safer, 'Emotional events and emotions in autobiographical memories', *In D. C. Rubin (ed.), Remembering our past*, 218–243, (1996).
[14] R. Clarke, *Asimov's Laws of Robotics: Implications for Information Technology*, Cambridge University Press, Cambridge, 1993.
[15] K. Dautenhahn, 'The art of designing socially intelligent agents - science, fiction and the human in the loop', *Applied Artificial Intelligence*, **12(7-8)**, 573–617, (1998).
[16] C. I. De Zeeuw, 'Time and tide in cerebellar memory formation', *Current Opinion on Neurobiology*, **15**, 667–674, (2005).
[17] J. Dias and A. Paiva, 'Feeling and reasoning: A computational model for emotional agent', *In: 12th Portuguese Conference on Artificial Intelligence (EPIA 2005)*, 127–140, (2005).
[18] A. Freud, *The Ego and the Mechanisms of Defence*, Hogarth Press and Institute of Psycho-Analysis, London, 1937.
[19] S. Gais and J. Born, 'Declarative memory consolidation: Mechanisms acting during human sleep', *Learning and Memory*, **11 (6)**, 679–685, (2004).
[20] B. Gert, *Morality: A New Justification of the Moral Rules*, Oxford University Press, Oxford, 1988.
[21] J. Gips, 'Towards the ethical robot', *Android Epstemology*, (1995).
[22] P. E. Gold, 'A proposed neurobiological basis for regulating memory storage for significant events. affect and accuracy in recall', *Studies of 'Flashbulb' Memories*, 141–161, (1992).
[23] S. Halpern, *CAN'T REMEMBER WHAT I FORGOT: The Good News From the Front Lines of Memory Research*, Harmony Books, New York, 2008.
[24] B. Joy, 'Why future the doesn't need us', *Wired*, **8**, (2000).
[25] J.F. Kelley, 'An empirical methodology for writing user-friendly natural language computer applications', *In: Proceedings of ACM SIG-CHI '83 Human Factors in Computing systems*, 193–196, (1983).
[26] J. LeDoux, *The Emotional Brain: The Mysterious Underpinnings of Emotional Life*, Orion Books Ltd., Phoenix, london edition edn., 1999.
[27] J. M. Levenson, 'Epigenetic mechanisms: a common theme in vertebrate and invertebrate memory formation', *Cellular and Molecular Life Sciences*, **63**, 1009–1016, (2006).
[28] Companions Project. http://www.companions-project.org/, 2007.
[29] The CHRIS Project. Cooperative human robot interaction systems. http://www.chrisfp7.eu/index.html, 2008.
[30] The ECIRCUS Project. Education through characters with emotional-intelligence and roleplaying capabilities that understand social interaction. http://www.e-circus.org/, 2007.
[31] The LIREC Project. Living with robots and interactive companions. http://www.lirec.org/, 2008.
[32] R. C. Schank and R. Abelson, 'Knowledge and memory: The real story', *In: Robert S. Wyer, Jr (ed) Knowledge and Memory: The Real Story*, 1–85, (1995).
[33] R. Sparrow, *The March of the Robot Dogs*, volume on line of *Centre for Applied Philosophy and Public Ethics*, The University of Melbourne, 2002.
[34] R. Sparrow, 'Killer robots', *Journal of Applied Philosophy*, **24-1**, (2006).
[35] Walters M. L. Otero N. R. Koay K. L. Syrdal, D. S. and K. Datenhahn, 'He knows when you are sleeping - privacy and the personal robot', *Technical Report from the AAAI-07 Workshop: W06 on Human Implications of Human-Robot Interaction*, (2007).
[36] E. Tulving, 'Recall and recognition of semantically encoded words', *Journal of Experimental Psychology*, **102**, 778–787, (1974).
[37] E. Tulving and J. Psotka, 'Retroactive inhibition in free recall: inaccessibility of information available in the memory stores', *Journal of Experimental Psychology*, **87**, 116–124, (1971).
[38] G. Veruggio, 'The birth of roboethics', *ICRA 2005, IEEE International*

Conference on Robotics and Automation Workshop on Robo-Ethics, (2005).
[39] G. Veruggio and F. Operto, 'Roboethics: a bottom-up interdisciplinary discourse in the field of applied ethics in robotics', *IInternational Review of Information Ethics*, **6**, 3–8, (2006).
[40] W. Wallach and C. Allen, *Moral Machines: teaching robots right from wrong*, Oxford University Press, Oxford, 2009.
[41] M. Wilson, 'Reactivation of hippocampal ensemble memories during sleep', *Science*, **265**, (1994).
[42] B. J. Wiltgen and A. J. Silva, 'Memory for context becomes less specific with time', *Learning and Memory*, **14 (4)**, 313–317, (2007).
[43] Lindfield K. C. Wingfield, A. and M. J. Kahana, 'Adult age differences in the temporal characteristics of category free recall', *Psychology and Aging*, **13**, 256–266, (1998).