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MODELING EMPATHY IN SOCIAL HUMAN-ROBOT INTERACTION

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Abstract

In the development of robotics, empathy appears to be an important aspect of social interactions. Empathy can facilitate the adaptation of robots in human environments. This thesis' goal is to model the workings of empathy in a social robot and explore different methods for future application. The field of knowledge representation and reasoning provides a lot of new insights for the future of robotics and could very likely be part of a future robots' brain. An ontology is a way of representing knowledge and different ontology-based methods are compared for different applications. The *ORO* ontology (and *minimalKB* framework) are evaluated most suitable for this project. A model is designed in an iterative fashion using different diverging methods that facilitate the so-called bottom-up approach. The method that is developed and presented is a theoretical picture of empathy in a robotic system. This model can be used in the development of empathy in robots. Finally, cooperation with J.Kuiken resulted in a model for empathy using associative memory; which is ready for further development.

Contents

Chapter 1

Introduction

The robotics world is growing and with that the robot-interaction and social robotics field are. Robots and robotic systems are widely spreading throughout the different public and social domains. The way an intelligent robot should act in different environments is yet to be defined, but there is a growing amount of studies discussing these topics. The field of social robot interaction is quite young, and placing a robot in an open space is a real challenge. There is already some research on social robotics in a closed setting, but in open-set conditions, a lot of the discovered results are not (fully) applicable [1] or require a lot more improvement: accepting new unknown information as a system appears to give a broad spectrum of new challenges. Different solutions to this problem emerge, where one important one is the practice of knowledge representation and reasoning.

In this thesis, the limits of social robotics are explored by considering the design of an empathetic robot. This robot could take any shape in any context and its goal is to be a functional helpful addition to a (public) space. This robot should, however, not (just) follow strict rules, but should be able to autonomously help anyone with the use of AI techniques. All while remaining interesting for users with the use of empathy.

This thesis aims to expand current knowledge on the methods for social robots with specific emphasis on the way empathy works. Since empathy is a mental construct, this thesis will mainly consider reasoning and cognitive functions of robotic systems.

A lot of knowledge is needed to properly design a robot made for the public space. A robot should behave in a certain way and should have a role in this social space. A robot should be able to make a conversation and show empathetic behavior. Therefore it is important to understand what the effects of empathy on humans are. Asada [2] states that empathetic interactions would lead to accepting robots in society and Leite *et al.* [3] considers the following describing future human-robot societies: *" To achieve this, robots must interact with people in natural ways, employing social mechanisms that people use while interacting with each other. One such mechanism is empathy, often seen as the basis of social cooperation and prosocial behaviour."*

For a robot to work, it needs some understanding of the world. We will attempt to approach this understanding via knowledge. Knowledge is a very broad basis of intelligence. The way information is stored in knowledge makes up its functionalities. Different goals could very well require different types of knowledge. Literature research aims to understand the empathetic behavior of robots and the use of knowledge. This thesis is built on top of the findings in this first chapter.

Research Questions

The goal of this project is to figure out how a social robot in the open public space could function while being considered empathetic and useful. Current knowledge on the brain of a social robot is still very limited, partly because science only barely understands the human brain: the thing we try to replicate. Our goal for the robot is for it to output empathy: leading to the question of how a robot could be programmed empathetic. But this is not covering the entire problem, namely, we should also figure out how a robot should *think* in the public and open space. With this, we know how and where to possibly implement this empathy. This all leads up to the following main research question of this research and design project:

Main RQ: "How could the reasoning of a robot be modelled for it to execute empathetic actions in an open space?"

To formulate a good answer to this question and come up with an answer, this question is supported by sub-questions. First of all, it is important to understand and define the domain we are working in, to be able to design for this domain.

SQ 1 : "How would interactions with this robot be?"

SQ 2 : "What kind of information does our robot need?"

Next to this, it is also important to figure out how the robots cognitive architecture should function:

SQ 3 : ”What are the required components/modules in the robots *brain* architecture?”

SQ 4 : ”How should knowledge be used in this architecture?”

And finally, we require to understand the functioning of empathy and how this should be contained in the design of the robotic agent:

SQ 5 : ”What is empathy?”

SQ 6 : ”How can we incorporate empathy in the design of our robot?”

This report

This report is split up into 8 chapters. These chapters will guide any reader through the process of the development of a model for empathetic robots. After this chapter, first, a broad literature review is done, to get a better understanding of the subject and present the state of the art. In Chapter 3 the methods used are all explained. This chapter also contains a brief explanation of the Creative Technology Design Process, followed in this thesis. Chapters 4, 5 and 6 contain the different phases of this design process and the final model can be found in section 5.4. This model is evaluated with the use of scenarios. In chapter 6 the model is merged with the work of J.Kuiken and evaluated. Chapter 7 presents a conclusion on the subject and thesis and contains a discussion considering the project itself and will give a quick prospect on future work done.

Chapter 2

State of the Art

In this chapter a literature research is done on several topics that are relevant for this thesis. The goal of this project is to figure out how a robot could be empathetic and social with the use of some knowledge representation techniques. This chapter consists first of all of background literature and a investigation in empathy and specifically artificial empathy (AE). Section 2.1.1 and 2.1.2 cover questions relating empathy. Next to this, there is also a literature research done on different methods of knowledge representation and reasoning. The findings related to this topic are written in 2.2.1, 2.2.2 and 2.2.3. Section 2.3 concludes the findings of this chapter and describes the value these findings have for the project. Finally in section 2.4 some specific related work is quickly discussed as a perspective for the project and to get insight in approaches to similar problems.

For both topics, questions are defined to guide the literature research. These questions are accompanied by a set of sub questions based on these topics.

Empathy in robots

When considering the Empathy in robotic applications, it is useful to understand the definition of empathy, the implementations and what its based upon, in the literature review an answer should be formulated on the following questions.

LQ: "How could Artificial Empathy (AE) be achieved and why do we consider empathy to be important"

LSQ 1 : "What are social effects of AE on users/interacting humans?"

LSQ 2 : "What techniques are used to achieve AE?"

Knowledge representation and reasoning

Also for the structural part of the robots brain, some research is done beforehand. In these sections an answer is formulated on the following questions.

LQ: "What are the different knowledge representation techniques and how do they facilitate reasoning and generalisation"

LSQ 1 : "What are the different frameworks and how do they work?"

LSQ 2 : "Why do we need knowledge representation in an empathetic robot?"

LSQ 3 : "In what domains/applications are knowledge representation techniques used?"

2.1 Empathy in robots

2.1.1 The need for implementing empathy in social robots

The implementation of empathetic behavior in social robots is widely discussed and there are various reasons, why in the design of a social robot, empathy should be taken into account. Asada [2] states that empathetic interaction is necessary for robots to be properly introduced into our society. He suggests, that this is the way, how robots could become part of our society and how social robots could be more accepted in society. Leite *et al.* [4] also recalls Breazeal [5] that in order for robots to properly become part of our lives: *"they should be able to communicate with people in similar ways people interact with each other"*. Damiano *et al.* [6] states that empathy is opening the possibility of interactions between humans and artificial agents. The adaptation of robotics in daily life seems to go hand in hand with empathetic behavior.

Empathetic behavior in human-robot interaction is especially positively affected when relations are of longer terms. Paiva *et al.* [7] states that interactions are more adequate, Leite *et al.* [4] also discusses the novelty effect and that this could be overcome with the help of empathetic behavior. Especially in long term relations robots are perceived more supportive [4] in a peer function: ratings of social presence, engagement, help, and self-validation remained similar over time, while otherwise, these would drop significantly. This could result in generating a more engaging interaction and likely add more value to the interaction. Over longer-term interactions, empathetic behavior has positive effects.

In the design and modelling of an empathetic behaving robot agent, the designer should be very careful to make a robot display adequate empathetic behavior. Misplaced empathy can result in several negative feelings towards the interaction. Both Paiva *et al.* [7] and Leite *et al.* [4], recall Cramer *et al.* [8], who state the negative effects in a bad display of empathy. He depicts that inaccurate empathetic behavior harmed trust, while, a more accurate display of empathy would result in the relations between user and robot as being 'closer'. Damiano *et al.* [6] reminds of the 'uncanny valley conjecture' [9]; stating when the resemblance with humans becomes too great, its positive effect is inverted and notes that the resemblance is not a determining effect in relation establishment. One should thus be very careful in designing empathetic behaviors, by making sure the act is adequate but also not nearing the 'uncanny valley conjecture'.

The adaptation of robots into the daily lives of people can only be done with the use of appropriate social and empathetic behavior. If an empathetic human-robot interaction is perceived as accurate, this has a large number of positive effects on the interaction, compared to human-robot interaction without the incorporation of empathy. Asada [2] reminds of the importance of *"affectivity"* in human-robot interaction. Empathy could therefore be considered an important step towards a human-robot world. In the specific application of the tour-guide robot, empathy should be implemented with care, which would require a good understanding of the environment, knowledge and memory of past interactions and an adequate model to display emotions.

2.1.2 Modeling of empathy in robots

When designing empathetic behavior it is useful to first understand human empathy and its mechanisms. Most designers go back to the core of empathy. Models of empathy are often based on the perception-action mechanism (PAM)[2], [4], [7]. Thus, before designing a certain model or behavioral system, it is important to understand the human equivalent: *"According to a PAM, empathy is defined as a shared emotional experience occurring when one person (the subject) comes to feel a similar emotion to another (the object) as a result of perceiving the other's state."* [10]. The start of designing a model is at the basis of PAM; "starting from emotional contagion and motor mimicry" [2]. Those core values are also discussed by Preston [10]: "representations of the emotional state are automatically activated when the subject pays attention to the emotional state of the object." Where she argues that most empathy in the PAM is subconscious behavior. Damiano *et al.* [6] however also notes that only the perception-action loop is not enough and insists on taking a broader approach. Damiano *et al.* [6] also notes that to *"artificially reproduce natural emotional processes in order to experimentally explore the role of emotions in the organization of behavior;"* would lead to greater autonomy and adaptation of robotic agents. A good understanding of human empathy is thus necessary to build a social robot. In designing a social robot, appropriate presence (motor mimicry, body language, etc.) and expressive empathy should be designed and human empathy is something that should be studied quite well.

One of the core aspects in modelling empathy seems to be mimicry: the behavior of copying the emotion or state of the object. Paiva *et al.* [7] suggests splitting up mimicry in imitation and afferent feedback. Where imitation relates closely to motor mimicry, while afferent feedback could be considered an active action of empathy. Paiva *et al.* [7] also supports the need for mimicry by introducing the term affective mimicry and by laying the focus on role- and perspective-taking. Mimicry can be achieved by creating simple loops based on the PAM, Leite *et al.* [4] created a model based on a Perception action loop, whereupon different extra parts of the model act on more complex empathetic behavior. Asada [2] also recalls the importance of synchronization of subject and object in an interaction, supporting the importance of mimicry in the behavior. Though mimicry seems to be a part of empathy, it also needs active actions to achieve a good representation of empathy.

A second core aspect would lie somewhere in an active act of empathy. Paiva *et al.* [7] describes the importance of empathy modulation, where mood, personality and social relationships are taken into account in the act of empathy. It is discussed that not only the state of the subject would be of importance, but also the representation of ones' own state (self). Besides this, also the different environments where interactions takes place seem to have influence on the matter. With this, the history of interactions between a subject and object matter [4], [7]. Leite *et al.* [4] confirms the importance of the use of memory in containing more long term relationships. This second, active part of the empathetic behavior is considered an even more important factor.

In making a deeper comparison between the empathetic behavior of humans and different models, Asada [2] makes a division between cognitive empathy (CE) and emotional empathy (EE). EE could be considered the more subconscious part of empathy, where emotional arguments and feelings play a bigger role, while CE is considered the active part of empathy, wherein reasoning and perspective-taking play an important role. Both, however, could only be achieved when a being is considered self-aware. This implying that an object of empathy can distinguish between the self and other state in order to adapt states from a subject. Leite *et al.* [4] also bases the *"Architecture of the empathetic model applied to the iCat robot"* on this assumption. However, in most current artificial empathy (AE) applications, determined or pseudo techniques are used. Leite *et al.* [4] use a predefined set of actions based on a simple algorithm with finite states. This, while real empathetic behavior in open-world situations can probably not be achieved by making a predefined set. Whereas these models provide a good basis, the development towards real empathetic robots seems to have a long road ahead.

2.2 Knowledge representation and reasoning

2.2.1 The need of knowledge representation in autonomous robots

When designing a robotic system for applications in the human-robot interaction (HRI) domain, the processing or 'knowledge' part of the system is also very important. In the Cyprus case this interaction should also be social. A robot in the social HRI domain could be applied as a peer in teaching to children [3], [11], could be an assistant for elderly [12, p.18] [12, p.21] [13], [14] or assisting in healthcre applications [13], [14], [15]. In development of this field these domains will only be extended to every application imaginable.

However when designing autonomous robots in these domains, there are quite high demands in terms of social capabilities of the robot agents. These systems should be able to properly understand their their surroundings and capabilities, and act accordingly. A robot agent should have a certain knowledge about its surroundings and be able to compute actions based on this knowledge.

A way of doing so is by using knowledge representation frameworks (KRF) and generalization methods integrated on those frameworks. A knowledge representation (KR) is considered: *"a means of representing knowledge about a robot's actions and environment, as well as relating the semantics of these concepts to its own internal components, for problem solving through reasoning and inference."* by Paulius *et al.* [16]. A KR is a method of giving high-level meaning to low-level inputs and outputs. Paulius *et al.*

[16] state: *"a robot should also understand similarly to how we as humans understand the world"*.

A different way of achieving social behaviour is by the use of cognitive architectures. Cognitive architectures are robotic architectures based on human cognition as a tool to help robots advance in this domain. There are already several different attempts, following different interpretations of human behavioural models; Asada [2] discusses different models through which human empathy can be described and based on those models, how artificial empathy could be acquired. Leite *et al.* [4] created a simplified model of cognition in empathy as an architecture for simple interaction.

Ideally both techniques are used in a complementary manner, paving a way to a more developed social interaction between human subjects and robot agents. (eg. in [12, p.18])

2.2.2 Applications of knowledge representation

Different domains of robot applications are already broadly explored and there is a broadening space for maturing knowledge based systems. Different applications however seem to require different methods to reach appropriate behavior. In this case, behavior can be defined as all higher and lower level output combined: so say, displacement of motors, sensor adaption, but also high level conversation or transferred conclusions by an autonomous robot.

In a lot of current research settings, autonomous robots with specific tasks in a (semi-) closed environment are being experimented on [17], [18]. Those robotic applications are used to develop platforms and more mature systems for robotic task execution. Robots of such are executing different tasks relating a lot to spatial understanding and displacement tasks [18]. Such settings have enabled the development of different frameworks such as the *Perception and Manipulation Knowledge (PMK)* [17], the *KnowRob framework* [18] or the *OUR-K framework* [19].

However, when dealing with robots in the healthcare domain, often a more social or conversation based approach is necessary in order to meet requirements. This does often mean that more focus lies on the application specific architecture and less on the knowledge based behavior [4], [15]. However, it does not imply that the knowledge is submissive to the architecture around the KB, but agrees on the fact that these two approaches should be combined in order to achieve a *good* HRI implementation. In the development of the IAMHAPPY well-being system, Gyrard *et al.* [15] integrates classifiers of physiological signal sensor data with a naturopathy recommendation application using knowledge-based techniques. In ACCRA, a project where robot agents are given goals in three applications of social robotics: Mobility support, Homework support and conversational settings, Fiorini *et al.* [13] base their system on FIWARE. FIWARE is considered a broad cloud platform that is: *"(...) a system integration approach between robotics devices and intelligent living environments, (...) , including the integration of robots, sensor networks, and handling data in the cloud."* The important aspect of architectures in applications in this domain is compatibility with a broad range of different IoT devices, sensor networks and cloud computing [12, p.21], [15], [13].

The integration with different tools can also be considered important in more specific applications in more industry related domains; such as in automated driving and nautical exploration [20]. In these domains full trustworthy autonomy is required. For underwater robots: Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs) Zhai *et al.* [20] implements the OWL ontology language and SWRL as the bases of their SWARMs ontology. Brunner *et al.* [21] is considering systems in the development of autonomously driving vehicles, where it requires a coherent understanding of the perceived context. In these domain-specific applications, it is very important that knowledge is both gathered and used in an appropriate way, demanding a high-level understanding of task and goal.

Lastly a vastly growing domain is the service robots domain. In this domain, there is also a large demand for integration with IoT devices and other sensors, since it is important to get an as complete as possible understanding of the environment. Lim *et al.* [19] states that different forms of robot knowledge should be fully integrated. Besides this, the methods used to describe the knowledge seem to be in need of expressiveness [15], [22]. This expressiveness is important for clearly connecting high-level in- and outputs in the specific contexts. In the design of the OUR-K framework Lim *et al.* [19] also mentions the importance of the ability of dealing with incomplete data. He also recalls the importance of cognitive capabilities, as does Ojha *et al.* [22]. The integration, high-level understanding and cognitive capabilities all are important aspects of robots in the service domain. For our case high-level understanding and a developed set of cognitive capabilities will be important aspects that we should keep in mind.

2.2.3 Methods of knowledge representation and interpretation

In the real comparison between different methods of knowledge representation one stumbles on the payoff between expressiveness and tractability of a knowledge representation language. This is already discussed by Levesque *et al.* [23]. They discuss the fact that there is no proven way of containing expressiveness as well as tractability of a language. One pseudo-solution they propose, is the improvement of computing power, which did improve a lot since 1987. However it also appears that the level of expressiveness of a language or system is not always a demand for a certain purpose. Take as example the Underwater robot purposed for exploration and mining in [20]. This robot is computing on a rather low level of expressiveness, allowing for more tractability, and supposedly quicker computing. This is because these robots would not be in the need for a high-level understanding of the tasks and whereabouts. A more social robot however, confronted with more complex high-level problems and maybe some social interaction does demand a much more high-level system. The level of expressiveness here is generally much higher. However, not only does the application domain generate different expectations from a system, also the kind of problems to be solved and the variety of these problems generate demands for a system (and its language).

In the table below 2.1, different levels of expected demands for expressiveness of the knowledge representation language and the parallel demands for their architectures are depicted. This expressiveness can be defined as how well a robot should understand its environment. Expressiveness is defined by the Oxford dictionary as follows: "The quality of effectively conveying a thought or feeling." If a representation is demanded to be more or less expressive, the representation has to describe more or fewer high level concepts. These concepts range from social interaction, emotions and relationships, to hardware, material knowledge and physiological knowledge. The latter being a lower level of expressiveness. Generally the closer a robot gets to the social space, the more expressiveness is demanded from its representation of knowledge: As it has to make more decisions that need a good understanding of these concepts.

Application	Demands of architecture	expr. level
Teaching to children	Social aspects, Social memory	+++
Assistant for elderly	Social aspects, Social memory	+++
Healthcare applications	Sensors, Connections to Cloud, IoT	++
Industrial	Sensors, IoT, Autonomy	+
Service	Social aspects, Sensors, IoT, Autonomy	++

Table 2.1: Application domains with demands and existing applications for system architecture/KRFs

As one can imagine, does the demand for a knowledge based system differ a lot between the different application domains. Besides this though, there is also a big difference in the demand concerning the system architecture. Integration with different technologies for example is much more a necessity in industrial applications then it is with say more social applications. This however is the other way around when we focus more on high-level social skills such as image recognition (emotion, facial, etc) and conversational text in- and output.

A last difference between domains, but also between specific applications is found in the processing structure. A lot of applications use next to the knowledge based techniques modules that work around this knowledge; such as modules concerning emotions, speech variety, task management and goal analysis.

Application	Demands of architecture	Methods, frameworks or ontology's	Sources
Social Companions	Social aspects, Social memory	ACCRA,Cognitive Architecture, SPARQL	[22], [13]
Healthcare applications	Sensors, Connections to Cloud, IoT	FIWARE	[13]
Industrial	Sensors, IoT, Autonomy	SWARM, PMK, KnowRob, CORA: CORAX, RPARTS and POS, SUMO, rosetta Ontology, Injury Ontology,	[24], [25], [18], [17], [20]
Service	Social aspects, Sensors, IoT, Autonomy	KnowRob, ORO, RoboEarth	[18], [24]

Table 2.2: Application domains with demands and existing applications for system architecture/KRFs

When considering different methods of Knowledge representation you'd inevitable would end up with some ontology. This is a way of describing knowledge by determining classes and 'connections' between these classes. Ontology's are useful since they don't require specific overall structure of a system. In an ontology rules are defined in all directions and this allows for different level use of properties. A lot of current systems have their knowledge representation based on an ontology [18], [22], [19], [21].

Next to an ontology, there are a lot of other ways of representing knowledge in a knowledge based system: rule based, Logic based (FOL), Semantic mapping, graphs and networks, taxonomies. These are however not completely independent from one another, since they are based upon each other or even work cooperatively.

2.3 *preliminary* Conclusion

When we look at empathy and the current state of the art on empathetic robots, they all have in common that empathy consists of both active and passive components. These components both exist in the perception action mechanism, which contains the perception action loop. This loop has first of all a passive component, which is an immediate response to an emotion shown by the subject. The active response is thereafter a well considered response taking the emotion of the subject into account. Currently, there is still very little work done to really achieve empathy in an autonomous robot and most projects rely on pre-programmed situations and action graphs. Empathy remains a very important aspect that many researchers consider a requirement for an appropriate human-robot society.

If we look at ways to do reasoning and have knowledge being used in a system, there are quite some approaches that could be taken. A framework of any kind we use or develop should be at least be able to integrate with some social elements/modules. Because we are trying to make a robot in the open space it makes all sense to use some knowledge representation technique. With the choice of technique and more specific framework of such, we should make a choice between tractability and expressiveness. In our case, probably quite some expressiveness is demanded: since we consider a social empathetic robot. This would however mean a loss of tractability and with that probably reasoning power. Most related frameworks are based on ontology's and the focus in the next chapters will also lie on ontology based knowledge representation and reasoning. This can be done specifically with the help of Olivares-Alarcos *et al.* [24].

2.4 Specific related work

Originally this project focussed on the design of an empathetic robot in a museum guide setting. This was supposed to only act as an example, but also provided a few very nice pieces of related work: these are likely a bit more specific than the previous discussed projects. With the help of these specific projects, we can get an idea of what approaches could be taken.

A first example is the interactive tour-guide robot Minerva [26]. The researcher here succesfully deployed a interactive and mobile robot in a museum. In this project, dealing with uncertainties was done with probabilistic algorithms. This robot has different layers in its software architecture, though interesting ones are the interaction modules. These determine the emotional state of the robot and the output the robot gives is based on this emotion. These modules exist on the second layer in the system; the top layer contains mission planning and scheduling. One other thing that is interesting is the fact that the system that runs Minerva is strictly decentralized, meaning that there exists no central control unit that manages everything. All modules also produce results based on available processing time, which could partly solve the problem of expressiveness enlarging processing time.

Another example is the tour-guide robot Jinny [27]. Where one of the goals of the project was to build a robot which "interaction system is spontaneous short-term interaction which can attract people around a robot and engages people's interests for no more than 20 minutes at best." In this project the robot also had an emotional state and some LED-matrix to express these. By a simple matching algorithm they performed minor associations to support the interaction. The interaction here is also based on speech and natural language. The association and processing is using a knowledge base and this is mainly to support the interaction.

Some other projects relating to this topic are [28], [29], [30], interestingly enough, most projects are very much concerned still with the overall architecture and specifically navigation through spaces. Currently those issues are still more relevant than the specific social interactions are. From Thrun *et al.* [26] and Kim *et al.* [27] we can already learn that researcher find it important for social interaction that the robot has some emotional state. This is then evoked and expressed in the interaction. Though, how these emotions are determined is still a bit unclear for now. Possibly interactions and empathetic behavior could solve this for a small part.

Chapter 3

Method

This project roughly follows the stages proposed in the Creative Technology Design Process [31]. With this structure for a project in mind, several techniques are used to facilitate the stages in this project. In the following sections first, the Creative Technology Design Process and the way it will be used are explained 3.1. Thereafter, different diverging methods used in this project are explained in 3.2, followed by the use of scenario's in a bottom-up approach 3.3. How knowledge representation and reasoning techniques will be explored is discussed in 3.4 and finally in 3.5 will be elaborated on the methods to evaluate the results of the project.

This project consists mainly of an ideation and a specification phase. In the final chapter, the goals stated in the introduction are discussed.

3.1 The Creative Technology Design Process

The methodology of this project starts very much in the core of the philosophy of Creative Technology. This core contains the creative process and explicit design methods [31]. Mader *et al.* [31] worked out a nonspecific design process for Creative Technology whereupon this projects methodology is based. This design process can be considered a rough sketch of the followings of a design process of creative technology projects (with mostly educational purposes). But what Mader *et al.* [31] also specifically recalls is the fact that this should just function as a tool in the discussion for what could be considered Creative technology; as this is an ever-changing field.

The Design Process proposed consists of four phases: Ideation, Specification, Realisation and Evaluation. Those phases all consist of diverging and converging methods. In this project, these phases are reshaped to the following: Ideation, Specification and Realisation and Evaluation, since this project has a more conceptual and theoretical goal than projects discussed by Mader *et al.* [31]. In the following sections, this approach is elaborated upon.

Ideation

Every creative process starts with ideation. Ideation is can be considered mainly a diverging process wherein the different possibilities are explored by the designer. Besides this, also different analyses are part of this ideation phase and are used to provide the designer with a broad understanding of the problem (and thus requirements for the design). The ideation of this project will be lead by a bottom-up approach to the problem. More on this will be explained later in this chapter.

Specification and Realisation

The Specification and Realisation are the logical follow up of a diverging ideation phase. Since the goal of this project mainly entails a model or proposed system, specification and realisation are very interrelated. Whereas specification very much relies on specific model analysis and mild design approaches could the realisation of such a model again be considered a convergence of the diverging specification. In this project, the actual physical building of a project is replaced with a refinement of the model and some minor applications in namely a theoretical approach.

Evaluation

These applications can, however, be very useful in the last phase; namely the evaluation stage. This phase should contain the evaluation of the model build and could provide useful insights into the further development of the model. This chapter also contains the comparison of methods and requirements that will be found along with the project.

3.2 Diverging methods

To grasp the full picture and allow for broad view, different diverging methods are chosen. These methods help in expanding knowledge and stimulate the creative process. The first method used is the use of scenario's and sketches to lay a foundation for the convergence in 3.3 where scenarios are used more specific. Next to this, also a system architecture sketch and brainstorm is done to get a good hold of all possibilities and analyze the current state.

Scenario's

Scenarios are sketched in big amounts together with J.Kuiken, in order to fully grasp what an empathetic robot could be. This is done mainly following the templates in figures 3.1 and 3.2. Where 3.2 is a simplified version of 3.1 which was considered to elaborate for the case. The different scenario's were sorted on application domain and a specific scenario was added, see figures 3.3 and 3.4. These scenarios are sketched to give a broad range of domains where an empathetic robot could exist. They also are to give a picture of domains that would be the first to have empathetic robots. Though, both personal robots and public robots are addressed. These scenarios are however the result of a brainstorm and we cannot consider this set to be complete. However, since they are designed in a cooperative fashion, with two quite different inputs, we can safely assure that a large part of the spectrum is covered.

<table>
<tr><td colspan="3">Domain: TEMPLATE</td><td></td><td></td></tr>
<tr><td colspan="3">Scenario:</td><td rowspan="3">Inputs:</td><td rowspan="3">Outputs:</td></tr>
<tr><td colspan="3">Description:</td></tr>
<tr><td>Needed contextual information:</td><td>Sensory:</td><td>Memory:</td></tr>
</table>

Figure 3.1: Scenario domain template a)

<table>
<tr><td colspan="3">Domain: TEMPLATE</td></tr>
<tr><td colspan="3">Scenario:</td></tr>
<tr><td colspan="3">Description:</td></tr>
<tr><td>Needed contextual information:</td><td>Sensory:</td><td>Memory:</td></tr>
</table>

Figure 3.2: Scenario domain template b)

Scenarios:
Scenario 1:
Action: Elderly is just sitting at home, forgetting what the next step was
Context: afternoon, call scheduled
Sensory: John, dreaming
Memory: There's a call scheduled, when john is dreaming he often is forgetting his duties and schedule
Output: speech/conversation
Exact output action: "Hey John, you have a call to make, remember! Your son is expecting a call in a minute."

Figure 3.3: Specific scenario example

Application domains

- **Elderly care**
- **Airport clerk**
- **Museum guide**
- **City centre assistant**
- **Supermarket clerk**
- **Education**
- **Household**

Figure 3.4: Scenario domain color-tags

The scenarios that are produced from this method can be evaluated and a few clear/good/well-evaluated ones can be used in the next step. Now a few scenarios can be worked out more and more specific, adding knowledge the robot might need, different in- and outputs, and their processing steps. More on this will be explained in 3.3.

System architecture

The second method to diverge is making different system architecture overviews in different layouts. This way different possible key-elements of the system can be discovered and because this thesis having a very exploratory nature, different approaches in finding the structures in systems are considered quite valuable. In the ideation, this method is first used to support the scenario's, whereafter it lays a foundation in finding dynamics that can later be used in possible solutions.

3.3 Scenarios in a bottom up approach

The scenarios that are produced by following 3.2 and the structures that followed from these approaches, can be used in a bottom-up approach to finding ways a robot could produce output. With a bottom-up approach, we start by defining the system very simple and from there define how it would produce outputs. This could then be projected on all layers the system or project contains. Two scenario's are specified and used to focus (see figure 3.5). One scenario is thereafter used as a lead in making a proper overview of the system and explore different ways of implementing empathy into reasoning dynamics. Based on these scenarios models can both be built and evaluated, as can requirements be achieved by analysing the scenarios and sketches.

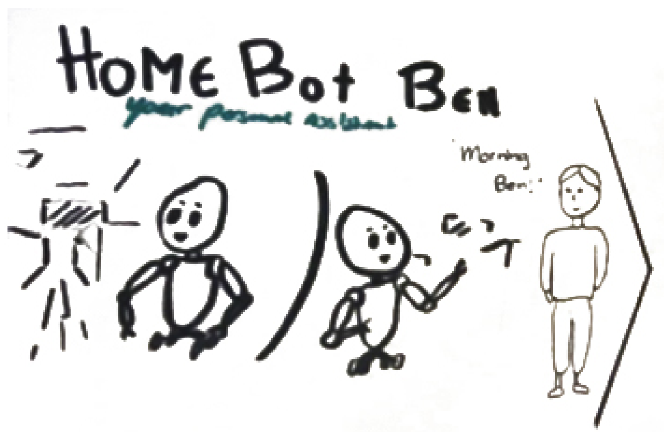


Figure 3.5: Example of a scenario sketch

3.4 Frameworks for reasoning

Except for theoretical models, this goal of this project also contains finding appropriate methods for possible future application. To be able to give proper direction, several analyses' will be done on different techniques and frameworks. To properly compare different frameworks, a set of values will be defined based on Olivares-Alarcos *et al.* [24]. These values will thereafter be compared with the models that describe empathy and can result in broad advice on what frameworks/tools/techniques to use.

3.5 Evaluation and iterative design methods

Lastly, the model that is built should be evaluated properly and with that, feedback could help improve the model. This will be done iteratively to improve the model and extract as many flaws as possible.

Evaluation of the model will be done mostly by implementing it on different scenarios. This way, it can be tested quite well if it is broadly applicable and what possible adaptation could make the model more applicable for future work. In the evaluation also an attempt is made to compare different existing frameworks and provide advice for future work on topics relating to this work. The evaluation will also consist of a small ethical report on the project, based on work done in the Reflection I and Reflection II courses. This will help place the project in perspective and allow any future work done to easily catch up with the ethical background of the project.

Chapter 4

Ideation

In this chapter, the different diverging approaches are discussed. These to facilitate ideation in the creative process. First in 4.1.1 and 4.1.2 the use of scenarios is discussed and how they formed a basis. Secondly in 4.2 a system architecture analysis is done and explained, which formed a proper understanding of the full picture. An overview and analysis is done on different ontology-based knowledge representation frameworks in 4.3 and 4.3.3. Finally the bottom-up approach is applied by investigating the problem goal interplay in 4.4.2 and 4.4.1. The chapters following this chapter are mainly based on findings in this chapter. This chapter can be considered an exploration of the different elements we are dealing with in this project.

4.1 Scenarios

In this section first (4.1.1) nonspecific applications and scenarios that are made for ideation are discussed, whereafter in 4.1.2, specific scenarios are discussed. These scenarios help in the process of understanding what a robot needs to understand. They are designed to both facilitate this thesis; where empathetic behavior should be incorporated in the reasoning of a robot, and, J.Kuikens' thesis where the focus mainly lies on associative memory. All nonspecific applications and scenarios are designed cooperatively.

4.1.1 Different application domains and scenarios

Every specific application is build up from the templates in figures 3.1 and 3.2. These applications are all connected to different domains, this in order to be able to generalize for more domains. With these different domains, also similarities and generalization were discovered. All applications are sorted by domain. The following domains were discussed and explored:

- Elderly care
- Airport clerk
- Museum guide
- City centre assistant
- Supermarket clerk
- Education
- Household

For every application a scenario is written (see figure 3.3).

In figure 4.1 a Household scenario is shown. In this scenario, the robot shows empathy by understanding the mental state of the subject. In this scenario, the memory would be a key function of the workings of the robot.

Domain: Household				
Scenario: home assistant - reminder			**Inputs**	**Outputs**
Description: This home assistant would remind you of your daily tasks and inform you over things relevant to you; some 'google home' like devices. It is present as a social go-to and just your personal assistant.			Conversations about emotional states and needs for the day/week. Certain goals etc.	Textual/speech feedback on tasks.
Needed information: Environmental data, social states,	**Sensory:** Speech, maybe vision	**Memory:** Social states (previous), the tasks (though probably linked to some calendar), things you like and current event links		

Scenarios:
Scenario 1:
Action: Sally comes home from the fitness and was supposed to do some gardening in the afternoon
Context: afternoon, rainy
Sensory: Sally, tired
Memory: Fitness is tiring, tired people don't like tasks, gardening is outside, being outside is not nice when it rains.
Output: speech/conversation
Exact output action: "Afternoon Sally, you were supposed to do some gardening this afternoon, but maybe postpone that to a more sunny day? Then you can also take some rest?"
/* if postponing, find a new spot in the agenda and propose that, else wish good luck.
…
Sensory2: Sally agrees on postponing, but asks for a simpler task
Output2: "Thats good, shall I postpone it to tomorrow afternoon?"
Output3: "Maybe you can then do the laundry now instead of tomorrow?"

Figure 4.1: A household scenario

In figure 4.2 an Education scenario is depicted. In this scenario, empathy is mainly achieved with the use of memory.

<table>
<tr><td colspan="5">Domain: Education</td></tr>
<tr><td colspan="3">Scenario: Peer (child)</td><td>Inputs</td><td>Outputs</td></tr>
<tr><td colspan="3">Description: The robot would act as a peer of a learning child. In this sense it would be empathetic and follow the track of the child peer-wise. It would learn together with the child and would recall on previous interactions</td><td rowspan="2">Conversation on the to learn matter, communication with the child, struggles and hickups, but also maybe mnemonics.</td><td rowspan="2">Supportive speech, hints and help, maybe provision of mnemonics and such.</td></tr>
<tr><td>Needed information: Educational matters of subject, learning progress</td><td>Sensory: Textbased, speech probably; text</td><td>Memory: Previous interactions, progress, struggles</td></tr>
</table>

** by rereading, I realize there is no specific need of application to education for children, in that sense it could as well be applied to adults or elderly*

Scenarios:
Scenario 1:
Action**:** Kid would be coming home from school and is starting with the homework.
Context**:** afternoon,
Sensory**:** Bob, homework on Maths
Memory**:** Bob has difficulties with Maths, Last progress was chapter 4.6 70%, Bob always forgets to grab some tea or lemonade before he starts.
Output**:** speech/conversation
Exact output action**:** "Hey Bob, ready for Maths today; at what question are we? Don't you forget your lemonade!"

Figure 4.2: An education scenario

A last relevant scenario is depicted in figure 4.3. Where a robot functions as a supermarket clerk. This scenario is worked out further in 4.1.2, to get a good understanding of possible dynamics.

Domain: Supermarket clerk		
Scenario: Stock clerk		
Description: The robot could be put to use in any aisle, stocking products in shelves efficiently. Customers can go up to the robot, and ask it to help them find a certain item. The robot can then relinquish its stocking duties for a while, have a short social interaction with the customer and show them where an item is located.		
Needed information: Store layout, item locations	**Sensory:** Hearing, speech, computer vision	**Memory:** Identifying features, past encounters

Example scenario:
Action: Person asks where the sugar is located
Context: Workday before dinnertime
Sensory: John
Memory: Familiar, usually shops with son Billy
Output 1: speech/conversation
Exact output action: “Hi John! Billy not with you today?
John responds with “Not today, he’s playing with friends until dinner.”
Output 2: speech/conversation
Exact output action: “I see, good for him! The sugar is located in aisle 4, halfway through the aisle on the left bottom shelf.”

Figure 4.3: A supermarket scenario

A set of scenario’s for different domains can be found in Appendix A. From these scenarios the role and importance of empathy and memory become quite clear. Also, it is now visible how empathy would be a result of some processing. In the following section, some scenarios can be worked out to fully explore the possible workings of a robot.

4.1.2 Specific scenarios

Two scenarios from section 4.1.1 can now be worked out into more specific scenarios. These scenarios are selected because they depict quite some differences between different domains. A robot can be either quite specifically focused and have interactions with few people, relying more on memory, or be more general and have shorter interactions with people. With two scenarios fro different domains, quite some things can already be generalized. Based on the scenarios depicted in figures 4.1 and 4.3 two new scenarios are sketched.

household robot

With the name HomeBot Ben, a scenario is created where someone interacts with a household robot.

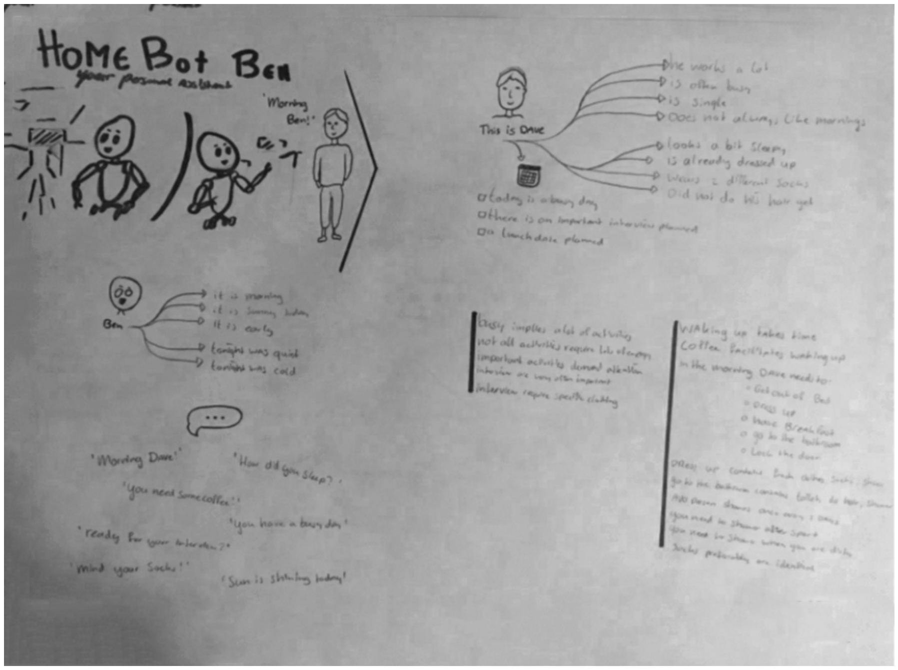


Figure 4.4: Scenario of HomeBot Ben

In this scenario, the robot functions as a reminder and home companion. The robot has specific information on the subject (Dave). This information is combined with insights into the calendar of dave. The robot also has information in its knowledge base, such as *Waking up takes time* and *Coffee facilitates waking up.* The robot however also is able to interpret some information: *it is morning, it is sunny outside, etc.*. A robot would be expected to, in this situation, greet the subject and maybe offer some coffee. Or the robot could remind the subject of his busy day?

supermarket robot

In the next scenario, the subject Marie interacts with a supermarket robot. In this case, the conversation is less personal and more general. Memory on certain information is, in this case, more relevant. The profile made of the subject (Marie) contains real-time information (such as *She does not look happy*) and memorized information (*She is here every week, she has kids of age* $\pm$ *10 y/o*). This is then combined with the information the robot can sense (current state), such as *it is afternoon, it is busy.* And combined with knowledge on lots of things: *People bake with kids*, *forgetting things is* *frustrating*, but also information more general like *afternoon, often people come after work*. This information all together should make the problem-solving in this specific scenario; namely, telling the subject the location of the sugar, also empathetic. Output clauses would also result in *"Busy workday?"*, next to *"The sugar is in aisle 3"*

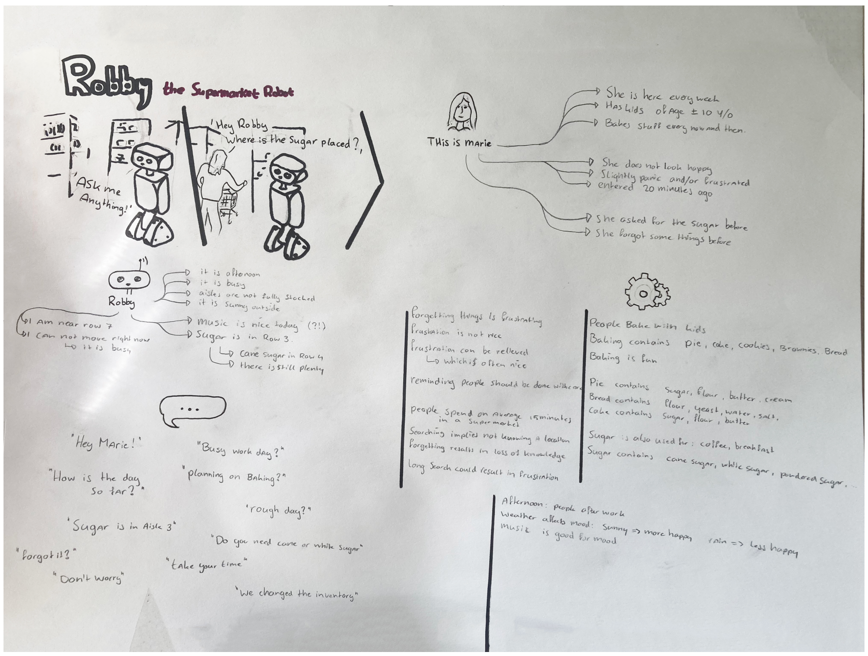


Figure 4.5: Scenario of Robby the supermarket robot

Both scenarios show well how empathy could change the robot, but also, what is needed in order to make a robot empathetic. More specific information on the subject, its current state and information on how to interpret and what to do with these *emotional* states are needed.

4.2 System architecture

To fully understand where possibly empathy could be implemented and what it may have as in and outputs, an analysis is done on the possible system architectures. This, of course, is a generalization of all possible applications. But with this generalization, the hope is there to capture as many systems by keeping it simple. In the analysis also some things are kept open; the inner workings of the robot. These inner workings are yet to be defined. In figure 4.6 the system architecture of a possible robot is shown. The inputs are constrained to a microphone, a camera, spatial sensors and possible communication with other systems. Outputs are constrained to a speaker, wheels and possibly a screen. The inner part of the robot can be split up in lower and higher-level elements. Lower level elements would be sound processing, environment map and active movement feedback. The important elements: the memory cell and the knowledge base, are connected through a *solver*. This solver controls the active state. Which is responsible for actual action tracking. Other found elements are an actuator of some sort and possibly the elements connecting to the environment map. This architecture is shown in figure 4.6.

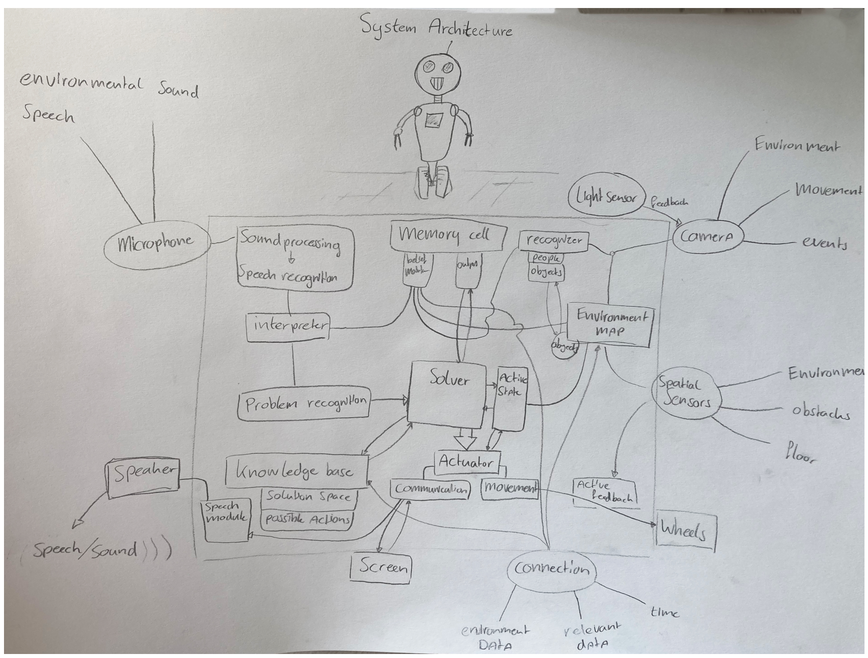


Figure 4.6: Analysis of the system architecture

Because figure 4.6 could be quite hard to read, an attempt is done to put it in a different form, namely a linear construction. This is depicted in figure 4.7. In this sketch, there is also made a comparison between higher and lower level links. For this project, especially the focus will lie on the high-level elements: The Solver, active state and the Memory. The knowledge base is not included in this figure, to be able to make a linear graph. This, of course, will remain important for the project.

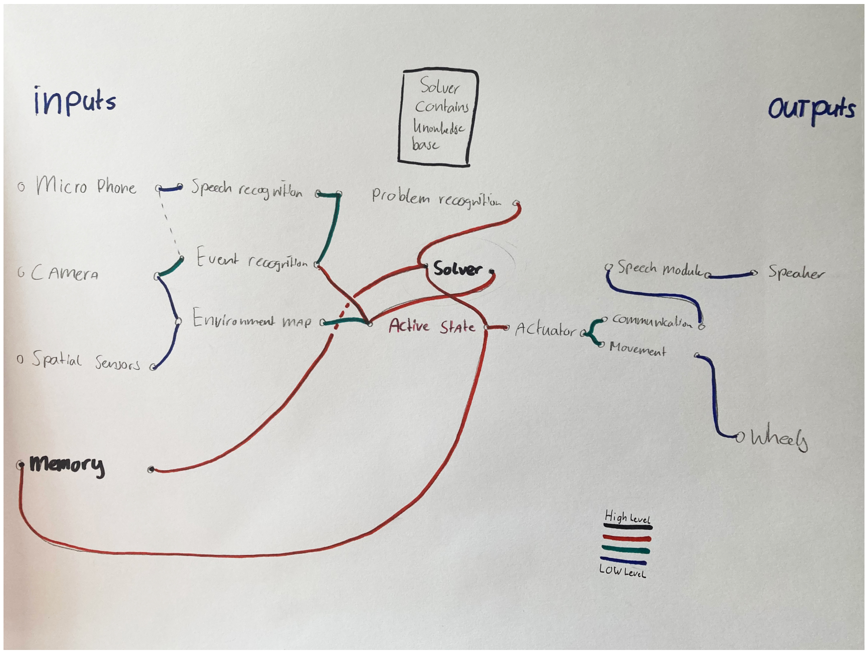


Figure 4.7: Linear expansion of the system architecture

4.3 Ontology's and frameworks to use

There's a wide variety of ontologies and frameworks that could be used by our robot in order to properly handle the knowledge. With this notion it seems like a good start, to first determine a good comparison method. This, to see what frameworks could eventually lead to a proper empathetic social robot. This section is based on the work of Olivares-Alarcos *et al.* [24] and slightly on work done in chapter 2.2. Olivares-Alarcos *et al.* [24] executed a very thorough review of ontology-based approaches in robotic applications.

Olivares-Alarcos *et al.* [24] also mentions an insightful reason for their work and with that the need for knowledge-based systems: "One of the biggest challenges is that every combination of task, robot and environment requires a specific robot control program. One way to make the resulting programming effort feasible is to adopt a knowledge-enabled robot programming paradigm." Where they project their vision on a future view with a large demand for specific robots. We should keep in mind that the comparison made by Olivares-Alarcos *et al.* [24] is focused on industrial and service robots. They start their comparison by picking a set of frameworks which knowledge is based on an ontology and reasons from this perspective, who are openly available, useful and applicable, properly documented and accessible [24]. This selection is considered quite relevant for this thesis.

4.3.1 Requirements and comparisons

First of all, does Olivares-Alarcos *et al.* [24] scope out in three separate scopes of comparison between the frameworks with ontologies.

The first scope is the ontology scope, where they focus on the notion of the following properties:

- Object
- Environment map
- Affordance
- Action and Task
- Activity and Behavior
- Plan and Method
- Compatibility and Skill
- Hardware Components
- Software Components
- Interaction and Communication

The second scope would be the reasoning scope. It contains the following qualifiers:

- Recognition and categorization
- Decision making and choice
- Perception and situation assessment
- Prediction and monitoring
- Problem solving and planning
- Reasoning and belief maintenance
- Execution and action

- Interaction and communication
- Remembering reflection and learning

The last scope contains the domain scope:

- Industrial robots
- Service robots

Since these scopes are quite broad and general, for this project we will only scope on a part of these scopes, that seem relevant for our robot. After we discuss these scopes and what we can use for it, interference is done with requirements acquired in the analysis. With these requirements then a conclusion can be drawn for both the demand and possible solutions.

Domain Scope

Service robot vs. social robot
Olivares-Alarcos *et al.* [24] only makes a comparison between industrial and service robots. Industrial robots would be any robots in the industrial context. A service robot would be any application where a robot performs a task for a human being, excluding the industrial applications. Now, in our case, the robot would be considered a social robot and not a service robot. However, the current field of ontology-based knowledge frameworks is quite limited and no full framework for social robots is existent within this scope. Olivares-Alarcos *et al.* [24] does include the notion of communication and it is not stated that any social applications are excluded from the comparison. For our case, the social aspects would be best encapsulated in the frameworks aimed at service robots: since these often require some social communication, or, at least exist in the social space.

4.3.2 Specific ontology-based frameworks

Olivares-Alarcos *et al.* [24] describes a broad comparison of nine different frameworks which process their knowledge ontology based. These frameworks/projects all have a different goal and/or approach. ([24] **KnowRob** is mainly designed for autonomous service robots and later, shifted towards the integration of simulation and rendering techniques into a hybrid knowledge processing architecture. **ROSETTA** stands for Robot control for Skilled ExecuTion of Tasks in natural interaction with humans; based on Autonomy, cumulative knowledge and learning. The implementation of ROSETTA is mostly on projects with the goal to create an intelligent support system for reconfiguration and adaptation of robot-based manufacturing cells. **IEEE-ORA** is a general ontology: This standard defines an overall ontology that allows for the representation of, reasoning about, and communication of knowledge in the robotics and automation domain. This ontology includes key terms as well as their definitions, attributes, constraints, and relationships. **ORO** was meant to enhance robot's interaction with complex and human-inhabited environments, where robots are expected to exhibit advanced cognitive skills, such as object recognition, natural language interaction, task planning with possible dynamic re-planning, ability to cooperate with other robots or humans, etc. **CARESSES** is a project focused on assisting elderly: the first robots that can assist older people and adapt to the culture of the individual they are taking care of. **RehabRobo-Onto** is an ontology focussed on domain-specific knowledge for Rehabilitation robots. **RoboBrain** is meant to be a large knowledge engine for Robotics, which learns and shares knowledge representations, for robots to carry out a variety of tasks. [32]. **OUR-K** is a framework, with the focus on the execution of complex tasks in real environments. Especially for service related tasks in indoor environments. [19] Lastly **OMRKF** is a framework from similar authors and is proposed to implement robot intelligence to be useful in a robot environment. [33]

4.3.3 What do we expect from an ontology

Now that we have these scopes, for some, we could make up a demand based on this project. This project is built around the design of an empathetic robot. This robot will live in the social space and therefor besides all the general understandings related to the general goal of the robot (such as helping people in a shop), a robot should have some social-space related knowledge/functioning. As well as the associative memory part (from J.Kuiken), that should be implementable or accessible.

First, we discuss the social space requirements: For a robot to function in this space, it should have knowledge on social and emotional concepts such as love, fun, affection, but also concepts like frustration and anger. These concepts should also relate to the general knowledge a robot possesses and uses. The affordance of the robot should be broad, in empathy, a lot of different options should be available to select the most empathetic one for a specific scenario. Actions should, besides being physical actions and/or digital, also contain acts of empathy: such as caring or relieving. Generally, we should aim for a robot with the capability to be social; this is not something a robot should necessarily understand concepts of. Lastly *interaction and communication*, these are important concepts as these are the main elements that partly define the social space. A robot should possess a broad understanding of these concepts and all that relates to interaction and communication. For the reasoning, it makes sense that the robot is able to recognize situations and relate these to the knowledge it has; this also relates to the associative memory part of J.Kuiken. Decision making and choice are elements of the reasoning, that should be adapted to empathetic decision making. A broad affordance would also result in a broader choice. Relating to recognition: *perception and situation assessment*. This should we also consider quite important as both the associative memory rely on this, as well as, any empathy. Empathy namely requires a well-defined understanding of the situation the robot is in. Interaction and communication, as discussed before should also be broadly interpreted in the reasoning of a framework. For memory, belief maintenance and remembering should be available; to be able to implement any form of memory, and specifically, associative memory.

4.4 Problem and Goal handling

In order for a robot to handle a certain problem in an environment, it needs to understand the problem and define a goal related to this problem or vice-versa. For this approach, it is first important to understand the general interplay between a problem and a goal. Loenhoud *et al.* [34] proposes a way of understanding this interplay; which will be discussed in the following section. In section 4.4.2 this high-level theory is conceptualized and in a primitive form this could serve as a base for a model that should solve problems.

4.4.1 Problems and Goals

The following is based upon the writings of Loenhoud *et al.* [34], who consider a problem as the following: "It concerns a present, negatively experienced state of an aspect in the stakeholder's context.", and a goal as: "It concerns an envisioned, future, positively anticipated state of an aspect in the stakeholder's context.". However, we cannot see one of both as separate entities as they are in evidently bound together, since the problem inhibits the goal.

goals

First of all, a goal is quite a broad concept in comparison to a problem. A problem can quite clearly be identified as some negative construct avoiding reaching the proposed goal. However, a goal, in general terms could be anything ranging from very specific (small) to very broad (big). For example, if we take the supermarket robot assigned to help people in a supermarket, its *top* goal could be considered raising overall happiness in the supermarket, while a *lower-level* goal could be ensuring Marie finds the sugar. We can consider the latter being a *child* of the first (or the first being a *parent* of the latter). In this manner, goals can be arranged in a taxonomic manner (trees). For the low level conceptualized applications, it makes sense to narrow goals down to the lower levels of the tree, but for understanding needs, it is logical to first leave this open.

risks

Both goals and problem are in any way interrelated and for any solving and actions to be taken, these should be identified first. This identification should result in a problem-goal statement. The problem in this statement proposes a risk. This risk is some goal that will be reached due to the current state, which conflicts with the goal in the statement. There are in general four things that can be done with a risk: avoid, reduce, transfer or take/accept. These are all so-called solutions to the problem in order to reach the goal.

solutions

Solutions can generally be considered the connection between the problem and the goal. This concept of solution can take one of the four forms previously described: avoid, reduce, transfer or take/accept the risk. As depicted in Figure 4.8 solution can, in general, be considered a way of solving a problem and something that achieves a goal. There are very often more solutions to a single problem and quite often solutions also provide new risks. Therefore we can consider solutions having some value (maybe in different labels).

actions

Up until now, all the discussed concepts are theoretical and have little real meaning in the real world. The last step to reach a goal is to execute an action. One or more actions are often contained in a solution. These can be executed. However, as also stated in Figure 4.8 is an action not specifically related to a goal and can very different goals be achieved by the same action.

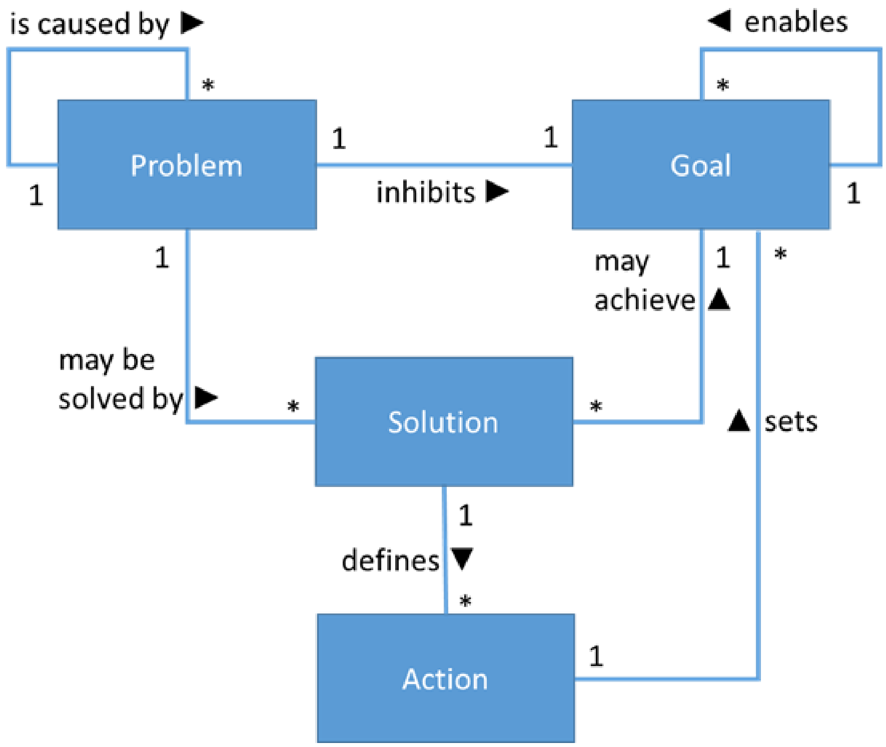


Figure 4.8: Simple problem solving model by Loenhoud *et al.* [34]

4.4.2 Conceptual problem solving in robotic application

We now have a general understanding of the dynamics that exist in a problem-goal statement and these dynamics can very well be useful in creating a system that tackles problems in our social empathetic robot concept. These should form a basis for the overall behavior of the agent. Consider the following scenario (from previously described scenario's): Marie is a young woman searching for sugar in the supermarket and asking the supermarket robot: *"Where can I find the sugar?"*.

The first step in this process will be identifying a problem-goal statement (see figure 4.9). How this could be done very much depends on the active input and could be split up in two likely possible scenario's: first of all, the active input could state a problem, where the goal is yet to be fully discovered. Secondly, the opposite could happen: a goal is stated, but the problem is yet to be figured out: since we need this full statement to find a solution. So, identifying these statements often not only requires active input such as speech or text, but also the current state of world variables. In this example, it may be useful to know where the sugar is located and that the question implies that Marie can not find the sugar implying that she is unable to find the sugar is the problem to be solved whereas the goal is that Marie ends up with sugar.

The risk connected to this problem is that Marie will not have sugar at the end, which implies that she is less happy when leaving. Though it depends on the solution space whether or not this risk can be avoided, reduced, transferred or taken/accepted. This solution space contains all solutions that may solve this problem and may achieve this goal (see Figure 4.8). This solution space, however, is shaped by both the problem-goal statement as well as by the current state of world variables. Imagine in the current example that the normal white sugar is out of stock, this would remove the solution of telling Marie the placement of sugar. This could maybe result in that avoiding the risk is no longer an option and maybe only reduced risks are contained in the solution space (such as showing her the cane sugar). Deciding which solution to pick can be mainly done through the idea that different solutions have a different value in different situations. This evaluation could very well be influenced by some module, such as an empathetic module.

Now if the robot has picked a solution, it could consider different actions that will lead to reaching the goal. These actions are most probably contained in the solution selected, but these should then again undergo a similar evaluation process based on the current state to result in proper behavior: such as empathetic.

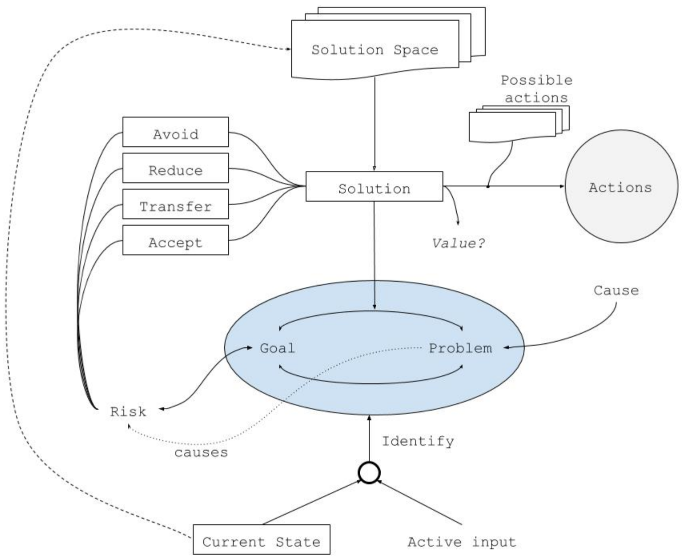


Figure 4.9: A model of problem solving

Chapter 5

Specification and Realisation

This thesis is attempting to scratch the surface of the future of empathetic robotics. The goal of this project lies somewhere in defining how empathy could fit in a robotic system. The design process towards an empathetic robot, however, requires a bit more than just a step-by-step instruction. First, a designer needs to be educated in several ways, as well as that he/she should go through different design processes. This chapter starts by specifying the mental dynamics described in 4.4.1. This mirror of human behavior and elements we could use are described in 5.1. How empathy could play a role in this design process and what should be prepared before actually starting with a design process is depicted in 5.2. How one would possibly implement this in an existing social robot is shown in 5.3.

With the help of scenarios explored in chapter 4.1.1 and 4.1.2, a model for empathetic behavior is presented in 5.4. This model is built with the help of the elaboration on the scenario in Appendix D. With these models in place, an evaluation is done in the next chapter to prove the model, and, to improve the model iteratively.

Finally in 5.5.1 the knowledge representation frameworks are compared on the different criteria shown in 4.3.

5.1 Problem and solution dynamics

Since the model in 4.4.2 is quite complex and hard to implement in a system, this model can be simplified. The previous model can be considered a theoretical model of how to deal with problems. To use this properly a more static approach is built, which can be implemented on scenarios quite easily.

This model consists of a simple problem, which defines a goal. This problem has several solutions in the solution space, which would define different actions to perform to reach the goal defined. See Figure 5.1.

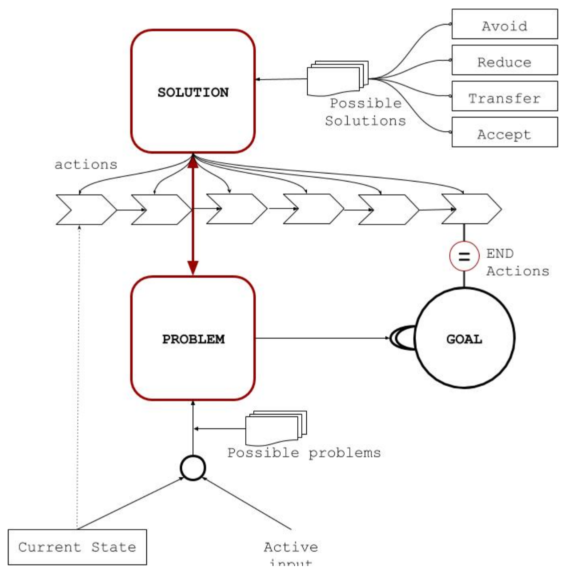


Figure 5.1: Problem solution dynamics to reach a goal

Problem

The problem should at first be defined, for the system to start reasoning and find a problem. This problem is defined by the active input (speech, gestures) and the current state (environment & knowledge). These together define a problem to be solved by the robot. This problem (coming from a large set of problems and goals,) then defines a goal state based on the systems knowledge. This goal state is the state wherein the robot should eventually end up, say, is believed to be true.

Solution

A solution can be picked based on the problem. A solution space contains different solutions that could help solve the problem to reach the goal. By reasoning one solution gets picked that evaluates possible, empathetic and useful in this situation. A solution contains different actions that all together lead to the goal state. Once this goal state equals the current state, the robot is done.

Reasoning vs. pre-programming

Part of the project is focused on applying knowledge ontology-based, which could be interpreted as taking out the solution space, that clusters the actions in different solutions. That way, it would mean clean reasoning to check for the next action. However, in that case, the system should reason a full set of actions without knowledge on how those work together. If a system could learn these solutions as sets of actions that effectively reach a goal, the processing effort could be greatly relieved. How this would completely work in a full system is not yet clear; as well as where what knowledge can be used.

Scenario implementation

To fully explore the functionality of this approach and see if there are aspects that could be worked out more efficiently, the model is hypothetically applied to two different scenarios. One scenario describes Robby, a supermarket robot that is supposed to help by-passers with some questions they have.

Inputs contain camera imagery, sound, spatial data and memory. With the use of inputs a problem is defined: `Object:Marie association:needs object:sugar` This problem then sets the goal: `Object:Marie association:has object:sugar` The sequence of actions in a solution can be halted once this goal is reached. Every problem-goal combination has a different set of possible solutions. These solutions may be chosen if the resolvent decides on this solution (`SELECT`). This solution then contains a set of actions to be taken to execute this task.

This pseudo approach is shown in Appendix B. Since it is just a pseudo approach and not meant for real evaluation but for mere exploration of the workings of the model, it is not completely consistent and can not be run in any way.

Having this sub-model in place, it can be further developed to implement empathy as well.

5.2 Empathy and Design

The mention of empathy is still quite vague and there is a lot that could be considered empathy as well as a large pile that is discussed. When designing an empathetic robotic agent it is important to state what this empathy contains; both for understanding and as support for the design process to fall back on. This definition will be used throughout the design phases and is based upon earlier findings in 2.1.

The basic principle of empathy that we will embrace is the concept of an agent (*self*) sharing (socio) emotional state with the subject of matter (*other*). This can either be by projecting the empathy of the self to the other or; and this is the more general definition; projecting the others emotional state on one's own. The latter will mainly be the one where the focus will lie on in the design process. This is because this is the most general and most recognizable form of empathy. (but we're not there yet)

Empathy in the agent should also be steered by the perception-action model (PAM). This model suggests that one's actions start by perception. All reasoning is done with this perception in mind and an action is the result of this. This will require any self to continuously be able to interpret emotional states of the other.

Lastly, most empathy can be split up into active and passive empathy; Where passive empathy entails mechanisms such as motor mimicry, this project the main focus will lie on the active mechanisms. These contain the active act of empathy and actively placing the others emotional state to the emotional state of the self. *The passive elements of empathy are still very important, but do not relate much to reasoning and could even be left outside of the reasoning of a robot.*

These prescriptions should lead to a simple more defined concept of empathy, which can be applied in the design of empathetic robots. Of course, in more complex and more developed agents, the for now neglected aspects of empathy could very well play a role.

Besides these assumptions, there are also more psychological aspects to consider before fully going into the design. For example the difference of empathy between cultures, the effects of empathy and the meaningfulness of an act of empathy when it is programmed. These will be discussed further throughout this section.

5.2.1 Designing empathy in robotic agents

In the design of the considered robot, often the word empathy is related to the demands for the robots behavior. This behavior should thus be empathetic. However, consider the following scenario: We have a robot in say, a park, where it is assigned to be a social assistant. In this park, a young girl falls over and is probably hurt, resulting in that she cannot get up easily herself. The social robot would then have a task containing something like helping her get up, asking how she is or calling her mom/dad. We could consider helping her getting up and asking if she is okay as an act of empathy, however, the goal of the robot: to help people in the park/be of social assistance also encloses those actions. So the label of empathy does not necessarily change anything. Neither can we remove the presence of empathy in this scenario, by for example changing the behavior since this is enclosed in our goal. The empathy in this robot can be considered embedded in its architecture in the sense that this robot's behavior is designed empathetic.

This could suggest that empathy is not so much controlled by a module or component of such. It could more be described as either something embedded in the design process or some sort of filter.

Empathy as part of design

In the case of empathy as part of design, empathy cannot be separated from the non-empathetic behavior. This could be a result of a high-level design approach, where the different cases are all prescribed in an empathetic manner and a robot's behavior is build up out of components which all are believed to be empathetic by the designer. This touches upon an important difference between this approach and the filter approach; namely that in empathy as part of design, the empathetic rules and statements are believed to be true by the agent; its knowledge is based on the statement of empathy as a truth, whereas having empathy as a filter, facts of empathy could be labeled as empathetic and empathetic would imply 'the right thing to do' or 'socially preferable'.

Empathy as a filter

You could thus also take the approach where empathy is only partly existent in your system. Different actions, assumptions and conclusions could be considered more or less empathetic. take for example the previous example: both asking if the girl is okay and calling her mom/dad could be considered empathetic since they both demand the agent to consider the state of the girl and attempt to resolve the problem. However, we can also understand that only calling her mom/dad can be considered a less empathetic action than (also) asking her if she is doing okay. You could, therefore, label the latter as empathetic while the first is closely related to the goal and only slightly touches empathy. Would the robot choose to be empathetic in this scenario it would ask the girl if she is okay.

To conclude: there are different ways of incorporating empathy in the design of a robotic agent; or at least different ways of looking at it. However, since it is hard to describe empathy as a separate module but moreover as a set of ideas spread throughout the architecture, it could be a hard this to make existing robots empathetic without changing its architecture. Though, when describing empathy as a filter, it could maybe be possible to create a set of rules that are believed by the name of empathy whilst others are believed by general rules of truth. This latter case could possibly also give a way for designers to change a social robot into an empathetic one.

5.3 How to implement Empathy

Most cases where empathy is demanded from a robot, already have some social robot in place and want to upgrade this robot to also be empathetic. It makes sense for these cases to try and define some sort of alternative approach. This, to also end up with an empathetic robot, without having to rebuild the entire architecture of a robot or system. Based on the scenarios and the specific scenario in appendix D. The steps defined below are also mainly based on the approaches taken in this thesis and this method should be evaluated properly to further prove the concept.

A scenario

When starting this design process, we start by defining a scenario. This will generate an understanding of what we mean by making our robot empathetic.

The first step to take is defining empathy; what does empathy mean in our scenario, what do we expect from the robot, etc. We should also first understand the environment we are placing the robot in: what people will interact with the robot, how do they live, what are their standards? This background knowledge will be required to succeed in the creation of empathy. Reasons specific to the latter will be discussed more in the ethical approaches in 6.3.

Next, we should specifically define the goal of our robot: what does it do, what are its workings and what should it achieve?

Now that we have this set, we can write down a scenario, for example: *Robot: "Ask me anything!" John: "Hey Robot, where can I find the milk?"*

With this scenario we should come up with lists for the following five points:

- Profile of human interactor (*subject*)

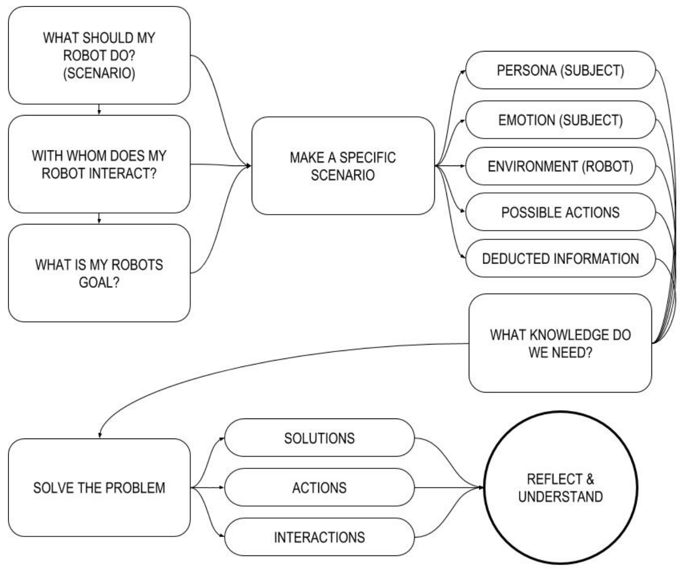


Figure 5.2: How to make your robot empathetic: Scenario

- Analysis of emotional state(*subject*)
- Analysis of environment states (*robot*)
- Interference of possible actions (*robot*)
- Deducted information related to the problem (*robot*)

If we have all this ready, we can add all possible knowledge/information the robot might need to get from this active interpretation of reality to some actions to undertake.

What is the specific goal in this scenario? Define this based on the general goal statement; for example,
global goal: make sure everybody in the shop can find the products they need.
specific goal: make sure john knows where to find the milk

Now we can come up with different solutions to reach this goal. How would the current robot solve this issue? With this, we can now sketch specific outputs/ output clauses. Sort these on *social, practical* and *empathetic.* Add to this, maybe some more complex outputs based on the memory the robot could have acquired.

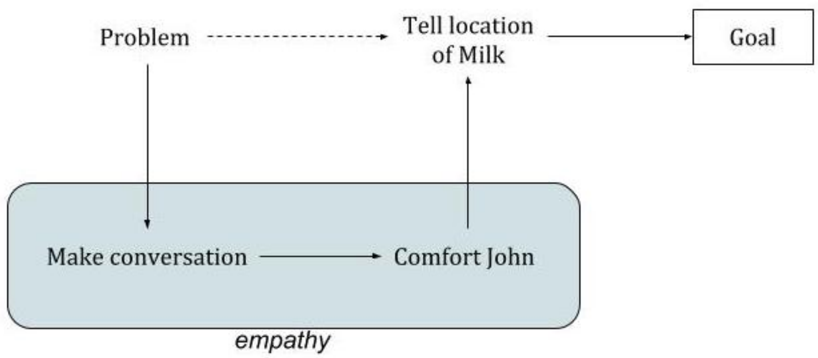


Figure 5.3: Example of how empathy might change a robot

Finally reflect on how the goal might have changed from a practical to an empathetic goal and how the solution has possibly become more complex (see figure 5.3). Answer how this robot now is empathetic.

System

Next, it makes sense to understand the existing system and identify all elements. First, the following four structures should be identified:

- Different input sources
- Different outputs
- System architecture in place
- Cognitive architecture

Now we can figure out what inputs might relate to our definition of empathy and we can figure out based on this definition, where empathy could be in the system: maybe the robot needs new information, knowledge or rules. Is there perhaps a place where an empathy module could function. Also, the robot should have some sort of pseudo-emotional state itself: what elements of the architecture would this be connected with?

Building empathy

The last step before starting to design an empathetic robot, is reflecting on the previous steps taken. We should now have identified what is still missing

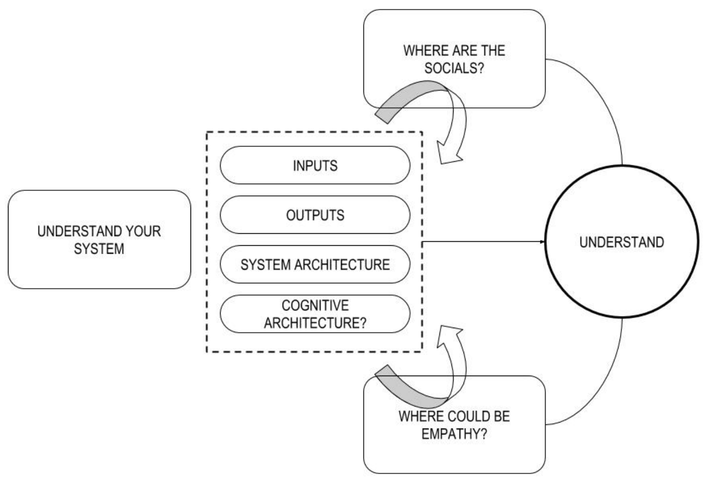


Figure 5.4: How to make your robot empathetic: System

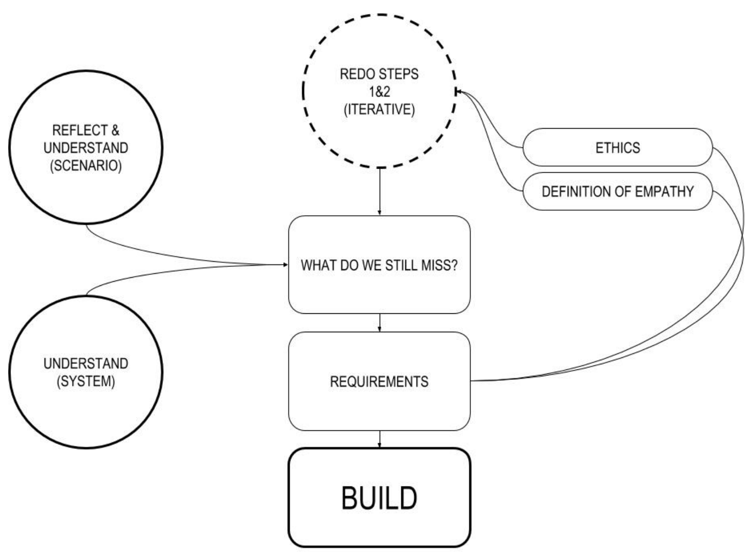


Figure 5.5: How to make your robot empathetic: Build

in our system and may have ended up with a set of requirements before the robot has empathy. In this last step, it is also important to reflect on what added value empathy has for the robot: is this value enough for the effort it will take?

This step by step approach is far from finished, but can be seen as the first draft or may just function as added value in a design process. These steps contain the most important elements of design I've learned during this thesis. Together with the ethical approach in 6.3, these steps could have real value in future scenarios.

5.4 A model for empathy in making social robots empathetic

We now have some approaches that could lead to a more empathetic robot. When we follow the problem-solution dynamics from section 5.1, empathy could be very well placed in a system.

5.4.1 Empathy as a goal

In section 5.1 a simple model is proposed to depict the problem-solution dynamics and solve the way a robot could handle problems. In this model, a problem is solved by a solution; which defines a set of actions, which transfer the current state to the goal state. In a simple scenario, the goal state could be a single topological state, such as the object sugar in the cart of a customer. This goal, however, quite often, would be a bit more complex: the goal could also contain someone having some information or a customer being happy. This would, of course, be then also contained by the problem that defines the solution picked. This is where empathy also comes in: next to having some goal like *Marie knowing where to find the sugar*, the goal state would also contain *cheering up Marie* or *Marie having a smile*. These different aspects of the goal state should all be reached together: which could very well be the implementation of empathy in the system.

5.4.2 *before* Implementing empathy

To formulate how empathy should be implemented in a robotic system, we should first recall section 5.2 and the ethical risks in chapter 6.3.

The first step in implementing empathy in robots is by informing designers properly about the different concepts of empathy. With this, the project should have a plan on what kinds of empathetic behavior should be implemented in the project. A good understanding by the designers must be achieved before trying to model and implement the behavior. Next to this, also cultural background should be understood by the designers.

5.4.3 A model for empathy

Based on all previous sections and the next section (D.1) we can now create a model that represents empathy, following a set of steps that can be followed. This model has been evaluated many times, to improve and extract its flaws. In Appendix C, previous versions and their evaluations can be found.

These steps are based on the explorations in scenarios and the previous findings in 5.1, 5.2 and 5.3. The final model is also polished with input from J.Kuiken and his model for associative memory.

Steps/elements to follow and base decision on:

1. Input clause
2. Define problem
3. Identify goal
4. Sense environment
5. Understand situation
6. Update states
7. Interpret subject
8. Let 'empathetic module' update goal
9. Define solution space (*sets of actions to reach goal*)
10. Resolve possible solutions
    (a) Regain information
11. Check for memory
    (a) is memory applicable
    (b) feed with memory
12. Evaluate possible solutions
    (a) Best solution

(b) Most empathetic solution
(c) Quick solution

13. Settle on solution
14. Check with empathetic module if this is empathetic
    (a) re-evaluate solutions
    (b) try with parallel actions
15. Start actions
16. Solution is in action
17. Keep the loop running and re-evaluate

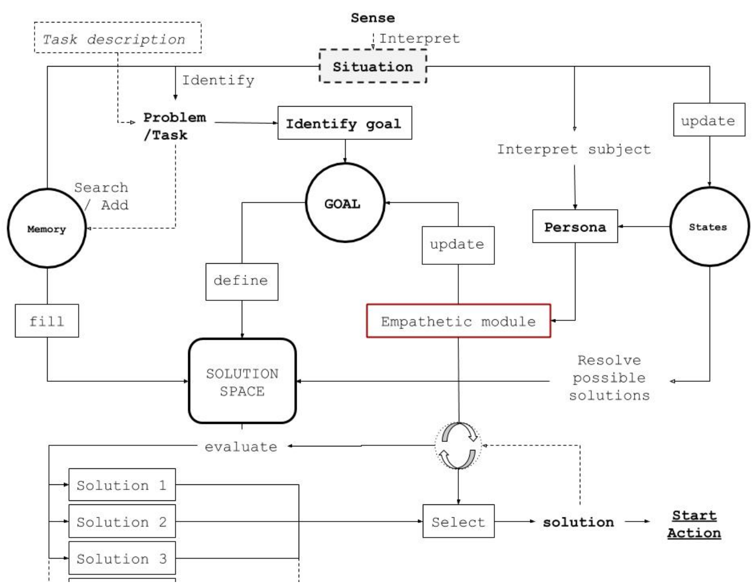


Figure 5.6: A model describing empathy in a solving system

This process described in the list can however not be fully explained in this linear fashion. Since processes should run parallel and continuous, it makes more sense to draw a model with it; this is shown in figure 5.6. In this model you can see how the different elements connect together. In this figure you can also see how eventually a solution is set to action. During the action the processes should however not stop. in figure 5.7 the processes and feedback loop during action are depicted. These follow the following steps:

Steps/elements during action:

1. Continuous active feedback
2. Keep track of emotional state
3. Check if goals are reached
   (a) is the default goal reached
   (b) is the emotional goal reached (*if not, store in memory and learn from this)*
4. store events in memory
5. feedback to solution space

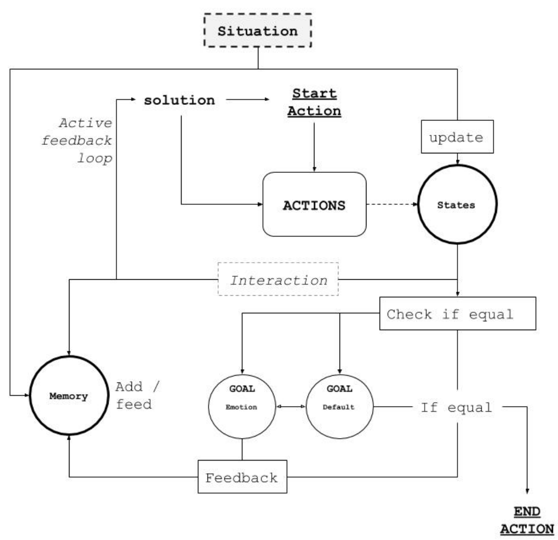


Figure 5.7: A model describing the active process of problem solving with empathy

This second model uncovers one more interesting thing, that emotional goals don't necessarily need to be reached. They will always be less important than the default goal. *unless of course empathy is contained in the default goal.*

In this model, we should elaborate four steps, in order to be clear on how the model works: What are the elements Empathetic module, Solution Space, Memory and Interaction.

Empathetic module

The module of empathy is fed with information on the current state the robot is in. This contains information on the environment, but more importantly on the subjects the robot interacts with: a persona. This specifically contains how a subject looks, how we interpret its emotions, etc.. This empathetic module then has two outputs. First of all, it updates the goal, with an emotional goal. Secondly, probably most importantly, does the empathetic module help with the evaluation of a solution and does it stimulate this active feedback loop, of continuous evaluation. The empathetic module has knowledge on what the values of a solution are and can select an appropriate one: Best solution, Most empathetic solution, quick solution, etc. Then in the selection, it also decides on what would, for this specific situation be the right thing to do. For example, John is in a hurry and a bit frustrated, frustration should be relieved by the rules of empathy and so is evaluated as an empathetic solution. However, in selecting a solution, the empathetic module 'understands' that John being in a hurry requires a quick solution: this understanding is an act of empathy. This empathetic module is thus a solver with specific knowledge on social and emotional values.

Solution space

The solution space is the main element of this model, where all knowledge processing comes together. First of all, it makes up a simple set of solutions based on the goal and problem, through reasoning. Next to that, it resolves first all practicalities, based on current states of the environment. Lastly it then also takes input from the memory to enrich the solutions it has. This solution space has both general knowledge and social/emotional knowledge. It could, for example, have the knowledge that being frustrated can be relieved by small talk (= emotional knowledge). The solution *small talk* is then enriched by the memory, which provides subjects to talk about and things to keep in mind: and also, maybe add solutions that weren't yet an output of the reasoning. All these solutions are then evaluated by the empathetic module and given some value on different aspects, say, empathy, practicality, appropriateness. This solution space would thus do most of the reasoning.

Memory

The memory model is fed with the problem and the situation and based on that can then output the relevant memory, that relates to any of these inputs. Whenever some (inter)action has happened, this is stored in memory. When a default goal is reached, the emotional goal is evaluated and the way this relates to the actual outcome is stored in memory: this way, the system can learn from previous interactions and when a similar problem occurs, it can better adapt with this memory on how the emotions react. The memory is always fed with the current situation and the interaction model. This, because the models describe a continuous loop and all that happens is fed to the memory. This way, it can relate the full picture to the memory it has.

Interaction

The element of interaction, contains a model of interaction, that is currently in progress. This would contain all environment states and events that happen or have happened. This would show how some events follow one another. This is both very useful as the input of the feedback loop as it is in memory, to store and relate to.

Tasks vs Problem

Depending on a system, it could be either task or problem-driven, or both. Different scenario pointed out that not all robots are just solving problems, but can also execute things related to their purpose: tasks. An example: The supermarket robot is mainly solving problems customers have, but a robot in a park with a goal to be a social point, does not necessarily solve problems but acts from its task description. These concepts though seems to be quite in parallel and therefore they could either or both be used. This would also make the model more applicable and general.

In Appendix D an elaborate overview of the scenario that lays the foundation to this model is shown. 5.3 is also referencing to this elaboration. Further explorations can be found in Appendix C. This is where the model is put to test as well.

5.5 Empathy and knowledge representation

The goal of this project contains making or modelling a robot with empathetic behavior. This, with the use of kn0wledge representation and reasoning (KRR) and specifically ontology's. However, most applications of ontology's in KRR are merely or even not focused on social interactions and social knowledge. This could be because of the current state of KRR not being quite as far in being able to make robots think that social interactions are added to the knowledge, or, the social whereabouts of the robot are not controlled with the use of knowledge, but differently in the cognitive architecture. There are likely two ways of how this field will continue and eventually involve social aspects (and with that empathy) in its systems: a) a separate social module(s) could be a way of steering the behavior of a robot socially, or, b) the social knowledge should be incorporated in the knowledge base with the use of different *Social ontology's*. Both could eventually be cooperatively used.

5.5.1 Frameworks

With the help of Olivares-Alarcos *et al.* [24], we can make some conclusions based on the criteria noted in 4.3.3. One thing that immediately jumps out is the lack of presence of terms like interaction and communication. These terms seem quite relevant for us but are not enclosed by any robotic framework or ontology. Further social aspects are also rare to find. The so-called behavior of a robot is also not stated or defined in any of the discussed frameworks. This does imply that a robot would not be fully self-aware using these frameworks. Being self-aware in some way does seem like a requirement for an empathetic robot: and this should definitely be examined more before a full empathetic robot is designed. Olivares-Alarcos *et al.* [24] states that most ontologies agree on the fact that there exists a relationship between Task and action: which could be useful if we look at the Task-oriented model presented.

Maybe, more importantly, are the actions of reasoning a framework or ontology supports. Yet, again, none define the term interaction and is thus not so much in line with our models. **ORO** is used to support object detection by disambiguating incomplete information extracted from human-robot interaction (Ros et al. 2010). CARESSES seems to include cultural knowledge and categorization of human-robot interaction, and human activity recognition. Especially **ORO** seems to focus on perception and situation assessment, which is very important for understanding full pictures and connecting with memory. **PMK** seems to approach this, but very robot oriented, without human activity or interaction relations. Olivares-Alarcos *et al.* [24] states that most frameworks are considered to have some form of belief maintenance.

On the reasoning side of communication, **ORO** is able to have a dialog with a human. **CARESSES** has examples where speech is used as interaction and **KnowRob 2.o** has some specific experiments, where human-robot interaction was one of the concerns.

5.5.2 Additions

In all cases, we still miss certain knowledge: let us consider a scenario where someone interacts with a robot in a supermarket. The robot, based on current systems would very well be able to figure out what a problem is and define a goal. A knowledge base could resolve this into solving the problem; though not empathetic or anywhere near social. The only social parts would be predefined combinations of outputs. The robot should however also take into account that the person defining a goal is in a certain mood (emotion). This should affect the decision-making process. Information such as that *moody people require a cheer* would be useful for a robot to know; but also information such as that *being moody has different sources; such as work, kids, bad relationships, etc.* and perhaps *Being moody should be solved.*

the social ontology

There is be a set of knowledge required to both facilitate different social interactions and allow the robot to add value to social concepts; such as emotions. This would, first of all, require background knowledge such as personal relations. A robot would need an understanding of relations between humans and the values these contain: The social ontology. Secondly, also value should be given to emotion theory and how we (the robot) can interpret, use and perhaps have emotions: the emotional ontology. An emotional ontology would be interesting though: different knowledge on the emotions of people and how these relate would be a useful start. A different piece of information would contain how to respond to different emotions. A last set of information would describe how a robot acts having different emotions. With this knowledge in place, reasoners that need to use this information (like the empathetic module), could be designed with more detail.

Chapter 6

Evaluation

In this final chapter, the findings of previous chapters are evaluated. First of all the model created in 5.4 is combined with the work of J.Kuiken on associative memory and this combined model is elaborated upon. Besides this, also the knowledge representation frameworks and other techniques discussed are given value and a piece of advice on this is produced. The chapter contains ethical viewpoints that I consider highly important considering the nature of this project and its possible future shapes. This chapter is concluded with an evaluation of the model using several scenarios from different domains.

6.1 A Memory model

This project is part of a collaborative project with the goal to make an empathetic robot with the use of associative memory. This thesis mainly focusses on the implementation and modelling of empathy. J.Kuiken worked on the associative memory modelling and build. In his work, he proposed a model for associative memory shown in figure 6.1. In this model, a situation is interpreted by focusing on all sensory input with the so-called attention. This would then result in having associations enter short-term memory. This short-term memory then filters and tries to associate with anything in long-term memory. These items of memory then are retrieved and have certain value: large or small associative value. These associations can then be used by the system.

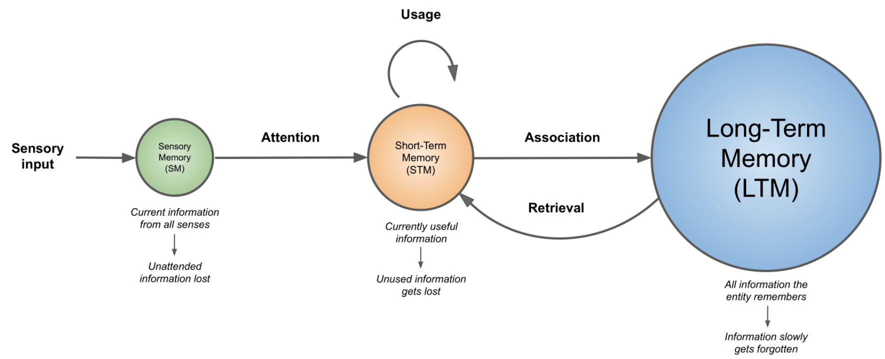


Figure 6.1: Model for associative memory by J.Kuiken

To include this in the model presented in this thesis, in a cooperative fashion both models are compared. Logically, these models would be connected on the Memory node. The Sensory memory in the Model in 6.1, can be compared quite well with the situation assessment in the model presented in this thesis. on this interference, the models are merged, as shown in figures 6.2 and 6.3. This situation node is invented during the session with J.Kuiken and proved itself useful in both models. In Appendix C, the *Input clause* and *Environment* nodes are still visible; these are merged to this situation box.

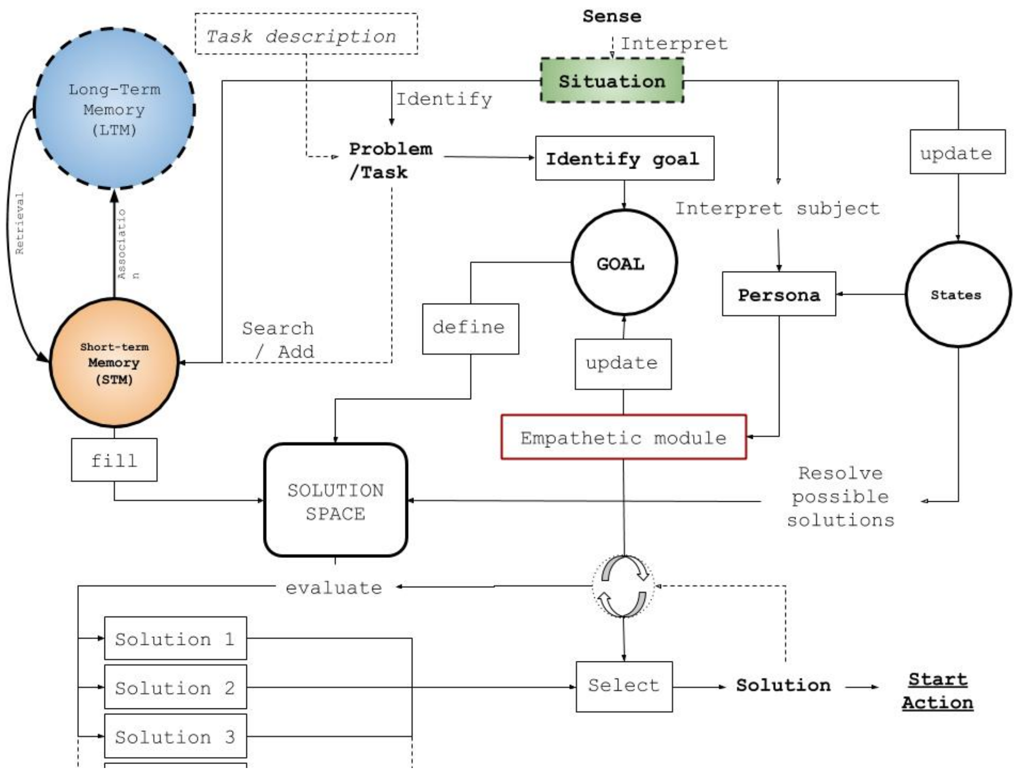


Figure 6.2: Associative memory in processing

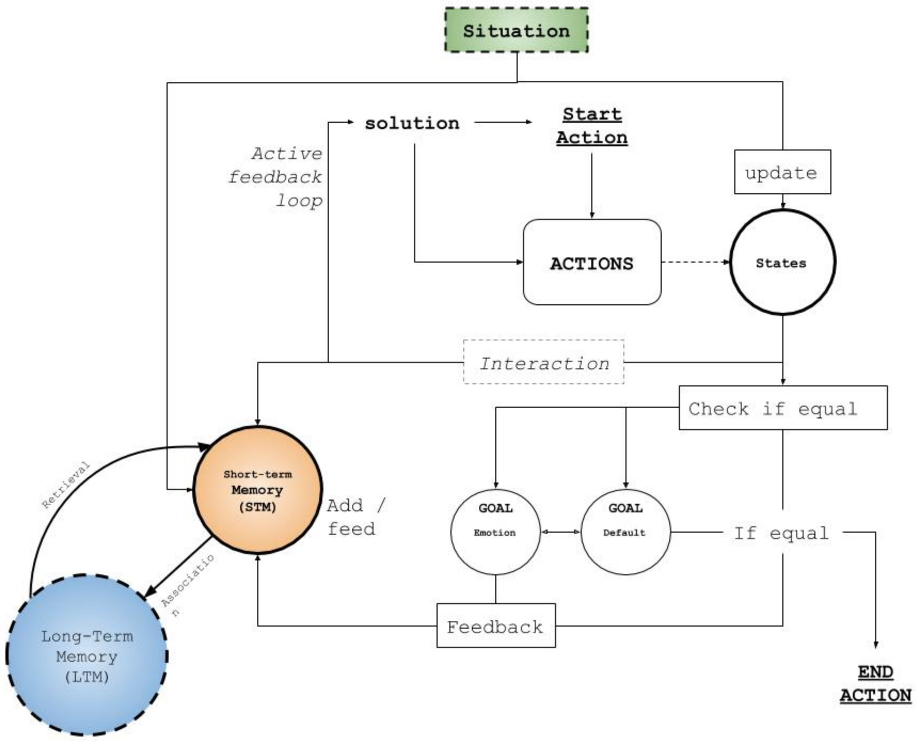


Figure 6.3: Associative memory in action

With this integration of models, the overall picture makes a lot more sense.

6.2 Knowledge - *implementing*

In a future application where empathy might become a part of the robot's abilities, we can choose to use different frameworks/ontologies. From 5.5.1 two projects seem possibly useful for the development of an empathetic robot: CARESSES and ORO. CARESSES is focussed on caring for elderly while adapting to the culture of the individual [24]:(Bruno, Chong, et al. 2017b), (Bruno, Chong, et al. 2017a). ORO, however, is a more general-purpose project, meant for development. This project seems to be more approachable for developers and designers. ORO is built upon the Open-Cyc upper ontology and is mainly written in java. There, however, also exists a lightweight version of the ontology, named minimalKB, which is based on python. Both are considered to be approachable and meant for understanding.

6.3 Ethical Issues

In this project often the focus lies on laying a foundation for future projects. These projects will probably have major impact on society and there are some ethical issues to consider: In the design of an empathetic robot. The following sections are adapted from the final report for the Reflection II class: "In the design of an empathetic robot: risks, an ethical perspective". The full document contains a broad analysis of ethical risks involved in the project: though a few are worth mentioning here as well.

Emotional Damage

The robot could, in some scenarios cause emotional damage to subjects that interact with it. This could first of all be in the form of some distress in short term interactions, but when people more often interact with the robot this damage could take forms as slight betrayal or disappointment.

In quick interactions, the robot could very well misbehave due to either the lack of information or a mistake or error in the software. This could result in someone believing the robot while it is giving wrong information, resulting in stress. Or, when the robot misplaces the emotion of someone, this person could be hurt by the inappropriate behaving. Since we are placing a robot in the open space, we could never avoid people passing by who experienced something the robot does not know about or could not anticipate on (since it can only be so complex). In these situations, the chance of giving the wrong output increases and the chance of causing some emotional damage is thus more present.

It could very well happen that someone passing by every day, interacts every day with the robot and they build some relationship; say, the person relies on the robot telling him/her the right weather. Since this social robot is supposed to learn over time and also recognize the persons they interact with, this relationship could very well be of some existence. In this scenario, emotional damage could be caused either by the robots architecture, where it presents misinformation or makes wrong assumptions, or, when this relationship is changed or even removed by the robot or its engineers. The person could very likely feel some sort of disappointment when being forgotten by the robot (or in the first case, when some information is remembered incorrectly).

Stakeholders and Empathy in context

In the design of a social robot, there is a big chance of ending up in a bubble. This could result in quite a misunderstanding of the users by the designers and engineers; but also maybe other groups that are somehow related to the product should not be forgotten. In an attempt to identify the different groups that are related, the following 5 groups are identified: Designers and creators, Investors, big company, Government , Co-workers: people that work in the same space as the robot and those who interact with the robot. The last two are quite important to take good notice of before starting the design process.

Co-workers: people that work in the same space as the robot If we stick with the supermarket example for a second. Where now a robot is situated to interact and answer trivial questions: This could result in a supermarket clerk becoming unnecessary, or maybe, lift all social interactions with supermarket employees. It could maybe also suddenly raise demand for the employees to somehow understand how to operate the robot or solve small issues, changing their qualifications. From the co-workers perspective, this could very well mean some sort of disruption in their work space. A robot suddenly is equipped with social skills and lifts some of those social tasks of your shoulders, which could be a pity or a relief.

Secondly those who interact: it concerns those who will interact with the robot. Ideally, this group consist of a very large part of a population; providing all kinds of people, with all kinds of interests and skills. For understanding, we split this demographic into three age groups: children and young adults (age 0-20), adults (age 21-65) and elderly (age 66-99).

First, let us consider children and young adults. These people are mostly very open to anything, don't mind trial and error and are curious. With a robot, they are interested and will try to push the limits with the system. They also don't mind that much if stuff is not working or works wrong. They mainly see the robot as a fun object, though probably don't consider it a useful addition.

When we consider adults, this group is the main target group, since it is both the biggest group and probably also the group most often passing by a robot in a public space. This group will be critical and; if the robot will not add value, they won't put in much of extra effort, most people at least. Every individual has its own schedule and priorities, extra time should be spend useful or fun. However, if the robot can offer some help in an empathetic way and this seems useful or nice. Why not check if it remains a good extra interaction every day?

Lastly elderly are a group that we should consider. This group is a bit slower and has patience. But this group generally also (or at least right now), has some aversion against new tech (or fear). This is important to take into account; since we are trying to add value to this space and not scare people. These people may very well consider a robot damage to a place. These people also very often live in a simple rhythm. We should be very careful in not damaging these rhythms and schedules, but moreover be a good addition, possibly also to the lonesomeness.

Dilemmas

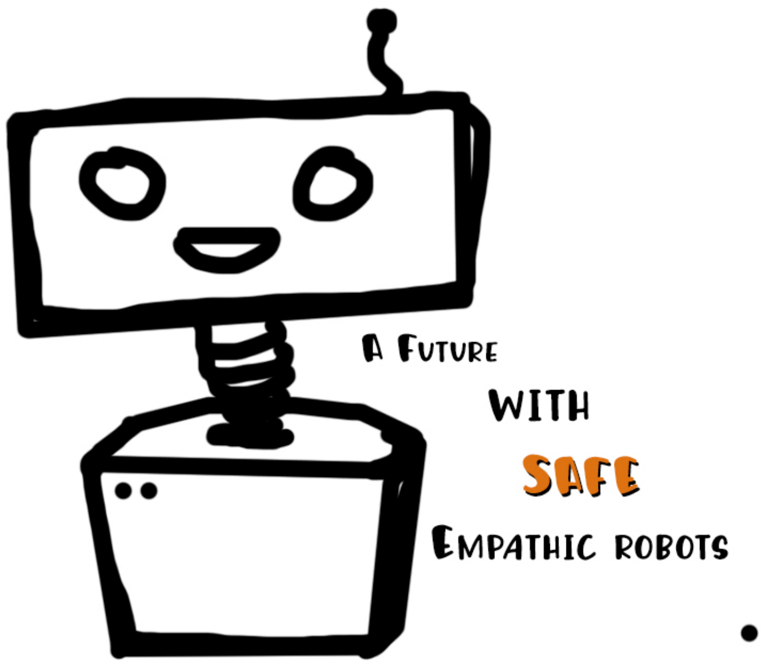
The main ethical concerns we are trying to solve are written below.

- Can a machine enter the social space?
- Can a machine be social and emotional?
- Can a machine (or something non-social) have social interactions?
- Is it right for humans to make social connections with non-human and/or human-made objects

Harm by and to robots

A last notion should be on how robots should behave in the social space. For this, the development of sex robots is quite interesting since it does quite literally what we are also trying to achieve: entering the social space with a social construct (*in our case empathy*): A last thing IBM states in their report on the code of ethics for chat bots is that the machine should prevent any human abuse: "a robot may not injure a human being or, through inaction, allow a human being to come to harm", following Isaac Asimov's's three laws of robotics. This is an ethics rule that is slightly abandoned in the development of sex robots. Where the systems often stimulate for abuse: In a workshop by Oliver Korn, they also question: "How would an artificial intelligence have to be adapted to serve customer needs without violating societal standards?"

It might be very useful to have several ethical viewpoints before starting this design process. In this case, the full document might be of help and can be provided on request.


A Future
WITH
SAFE
Empathic robots

6.4 Evaluation of the Model

With the model in place, the scenario's that are created can be used to evaluate the model and see how the model can be applied in different domains and scenarios. First, two scenario's are picked and used for evaluation, where they point out an important difference. This difference is then tested in two more scenarios from different domains.

Scenarios

The first scenario is shown in figure 6.4. This scenario describes a rehabilitation robot, interacting with Jeff:
When we look at this scenario, we can assume a robot with this purpose has some knowledge of rehabilitation topics and has some module that keeps track of the medical state and progression. The task description for this robot is quite clear and steering; helping rehabilitation. The situation block would contain the entering of Jeff and the time for rehabilitation. The task description would resolve this to starting a rehab program and the goal set to Jeff having done his rehab. Empathy would add to this goal, to take Jeff into account and see if he is doing ok: otherwise, you might have to take a slightly different approach. Memory would add the downfalls and information on previous sessions that might be relevant. The solver of the solution space should have this logic/knowledge base for rehab, so it can resolve all inputs it has to a proper rehab scheme for today. In the action phase, the feedback loop the solver gets updated on the activities: whenever the default goal is reached, the system can compare the emotional goal with the current state and see how it performed. Is the steering done well? Make the association with memory that the actions taken have resulted in this emotional state: next time take a similar/different approach.

The second scenario describes a museum clerk/guide robot that should answer general questions. This scenario is shown in figure 6.5:
In this scenario, we can assume the robot has some general knowledge as well as some specific museum knowledge. We can also safely assume it is connected to the sensors/system of the museum to gain information. In this case, the situation can be interpreted and would define a problem to solve. Besides the default goal to get Jeff to his son, the robot does also take into account the persona (/w emotions) of Jeff. This shifts the goal from only finding the kid, to helping him not getting worried and hopefully leaving pleasantly. The solution space is also filled up with information that

<table>
<tr><td colspan="5">Domain: Elderly care</td></tr>
<tr><td colspan="3">Scenario: Rehabilitation assistant</td><td>Inputs</td><td>Outputs</td></tr>
<tr><td colspan="3">Description: In this scenario, the robot has the task as a supportive system in the rehabilitation process. A robot could give feedback on exercises or even be the leading agent in the process: so the robot would monitor and construct the rehabilitation. The robot would tell the subject what exercises to do, maybe by showing a screen or some other output mechanism. It would capture the movements of the subject and incorporate that in the feedback and the general processes of the system</td><td rowspan="2">The social state of the subject as well as visual input on the actual rehabilitation.</td><td rowspan="2">Exampling movements (visual), text/speech on the actions to perform, text actions on feedback, social text: supportive, empathetic.</td></tr>
<tr><td>Needed information: Medical background on rehabilitation, social context, social skills applicable to this domain</td><td>Sensory: Computer vision, speech, text</td><td>Memory: The current state of the process, personal feedback</td></tr>
</table>

Processing:

-
-

Scenarios:
Scenario 1:
Action**:** Elderly is ready for the rehabilitation, said that het is ready
Context**:** morning, after breakfast,
Sensory**:** Jeff, speech recalling he is ready
Memory**:** Last exercise was yesterday, progress is 45%, health is going up
Output**:** speech/conversation + screen illustration
Exact output action**:** "Morning Jeff, how are you feeling, you seem to be progressing well!"
/if feeling well; start with the exercize, else update the exercise to feeling & update progress
…
Sensory2: Jeff recalling that he is doing ok
Output2: "Thats good to hear!, lets start with this exercise to warm up … can you see mee clearly? … "

Figure 6.4: A scenario depicting a rehabilitation case

<table>
<tr><td colspan="5">Domain: Museum guide</td></tr>
<tr><td colspan="3">Scenario: Front desk/ help</td><td>Inputs</td><td>Outputs</td></tr>
<tr><td colspan="3">Description:
This social robot would funcion on the front/entrance of a museum, where it would be able to help by-passing tourists/ visitors with anything that bothers them: finding the restrooms, having lost a jacket, getting information on the current expositions. This robot would be able to generally help people with their problems, or route them to a place where the solution is likely to be.</td><td rowspan="2">Textual problems a bypasser is bothered with. Topographical questions</td><td rowspan="2">Textual (could be speech) outputs to help the bypasser. Maybe some gesturing feature could facilitate a lot of questions that require movement from the subject to another place.</td></tr>
<tr><td>Needed information:
Environmental data, up to dates on the museums whereabouts.</td><td>Sensory:
Visual, computer vision, speech,</td><td>Memory:
On identical situations, previous solutions, social interactions and recent problems</td></tr>
</table>

Scenarios:
Scenario 1:
Action: Someone called jeff lost his kid in the museum
Context: afternoon, busy
Sensory: Jeff, slight panic
Memory: Busy days, kids often go to the kids corner, intercom could be used, people with panic should be calmed.
Output: speech/conversation + intercom + screen
Exact output action: "Hey Jeff, don't worry we'll find him, what's his name? " + Request camera image of kids corner
/* name = x, first show camera image; If jeff calms down, continue, else request for human assistance
...
Sensory2: Jeff recalling the name of the kid (Bob)
Output2: "Thanks, could you maybe look on my screen and see if bob is in the kids corner?"
/* if kid not there, use intercom. Else tell directions
...
Sensory3: Jeff confirms seeing bob in the kids corner
Output3: "Thats good! You can get there by taking these stairs down and walking straight from there! Just follow the signs!"

Figure 6.5: A scenario describing a museum clerk/ front desk help

associates to this problem: "..., kids often go to the kids-corner, intercom could be used, . . . ". These have a high associative value and thus can be tried first. When we enter the action phase, new input from jeff, of course, changes the course of action via the feedback loop. The interaction and its result: "Jeff confirms seeing Bob in the kids-corner" are again added to memory to make associations.

When we compare both scenario's, we can see that the model is quite applicable in both cases, yet does the second case make a bit more sense, mainly because the model is problem-focused. The difference between both scenarios is also that the first scenario describes a robot that delivers very specific interaction to one or a few persons, while the latter interacts with tons of people and has a more general nature. This more general approach seems

Domain: City centre		
Scenario: Hotspot information		
Description: The robot would be situated at a specific tourist hotspot. It would give tourists who come by more personal answers to questions that might not be on general signs.		
Needed information: General city information, city history information, information about the touristic hotspot	**Sensory:** Hearing, speech, computer vision	**Memory:** Past encounters, past questions and answers to those questions

Example scenario:
Action: Person asks the most interesting fact that most people don't know about the hotspot
Context: Holiday
Sensory: Tess
Memory: Familiar, is interested in history
Output: speech/conversation
Exact output action: "Hi Tess! Something most people don't know about X, is that Y happened to it in YEAR."

Figure 6.6: Scenario of a robot as hot spot information provider

to suit the model a bit better and domains that require a general approach of interaction are quite possibly easier approachable using the model. This general approach is also possibly easier to experiment with and make generalizations during development. Next, two more domains are used to evaluate the model.

The first scenario comes from the city-centre domain and depicts a general interaction with a bypassing tourist, see figure 6.6:
In this scenario, the robot has knowledge on the different "General city information, city history information, information about the touristic hot spot" or perhaps some connection to a larger set of information. The situation defines a problem quite nicely and the robots only goal here is to get an answer on the question; the empathy is quite implicit to the task description, but could very well tune the goal into taking into account the person's interests. Memory should fill up a lot of gaps both on the association level as on specific personal information. In action, the default goal, of course, has priority, but this cycle makes quite some sense here. The interaction profile can also relate quite well, though, interactions are quite short and simple in this case. The next scenario describes a robot that acts as a peer in an educational setting, see figure 6.7:
In this scenario, the robot is focused on Bob specifically. The robot probably has some knowledge of education and might even be in contact with some system of the school: that keeps track of Bob. The situation, in this case, is part of a long upcoming interaction: the situation would contain

<table>
<tr><td colspan="5">Domain: Education</td></tr>
<tr><td colspan="3">Scenario: Peer (child)</td><td>Inputs</td><td>Outputs</td></tr>
<tr><td colspan="3">Description: The robot would act as a peer of a learning child. In this sense it would be empathetic and follow the track of the child peer-wise. It would learn together with the child and would recall on previous interactions</td><td rowspan="2">Conversation on the to learn matter, communication with the child, struggles and hickups, but also maybe mnemonics.</td><td rowspan="2">Supportive speech, hints and help, maybe provision of mnemonics and such.</td></tr>
<tr><td>Needed information: Educational matters of subject, learning progress</td><td>Sensory: Textbased, speech probably; text</td><td>Memory: Previous interactions, progress, struggles</td></tr>
</table>

** by rereading, I realize there is no specific need of application to education for children, in that sense it could as well be applied to adults or elderly*

Scenarios:
<u>Scenario 1:</u>
Action: Kid would be coming home from school and is starting with the homework.
Context: afternoon,
Sensory: Bob, homework on Maths
Memory: Bob has difficulties with Maths, Last progress was chapter 4.6 70%, Bob always forgets to grab some tea or lemonade before he starts.
Output: speech/conversation
Exact output action: "Hey Bob, ready for Maths today; at what question are we? Don't you forget your lemonade!"

Figure 6.7: Scenario in education domain

the homework on math and Bob being here. The empathetic module takes Bob into account and makes sure the robot goes at Bob's pace. The solution space, in this case, has more a form relating to some control unit, the overall process is defined, but the specific steps need to be evaluated. In Action this interaction is fed to the solution and perhaps the big goal of having Bob done chapter 4.6 can be split up into different sub-goals. The single goal dynamics make a little less sense in this situation.

Applicability

With both the first two and the second two scenario's, we can see that the model works better for some cases than it does for others; specifically in cases where a large number of small interactions exist, the model seems to work pretty well. When we are however dealing with longer interactions, which are often more task-driven and rely on some process, the full model does not always seem like the easiest option. For these cases it may be beneficial to first develop a set of scenario's that all focus on these processes during an interaction (such as a rehabilitation process); and then, change the model in an iterative fashion, to shape it. However, the empathy in

these scenario's, as well as the memory, still make sense. Just the base problem-solving model, does not seem to fit entirely. A different approach could therefore also be, to redo a bottom-up approach on task-driven action and processes. With models that come out of this process, empathy and memory can be again implemented, just like in this thesis.
When we quickly look at the different domains addressed, this model thus mainly applies to domains requiring general approaches, such as *Airport, Museum, City-centre and Supermarket* and might be a bit less applicable to the domains: *Elderly care, Education and Household.*

When we look at the general cases, the model seems to be quite well-applicable and might serve as a nice foundation for design practices in this direction.

Chapter 7

Conclusion

The goal of this project was to make a model for empathy for a robot in the open space and figure out how this robot would work. In this thesis, the possibilities and dimensions of empathy are explored and used in several ways. Concluding from the state of the art empathy is a quite necessary element a robot should master when we strive for a human-robot society. Empathy is an important aspect of social behavior where both passive and active mechanisms have their own important roles in. In this thesis, the active act of empathy is used in a bottom-up approach and with the help of many scenarios a model for the active mechanism is designed. This model is iterative reshaped and most flaws are extracted to make a powerful model for several applications. In these applications this model accompanied with reasons given prior to the model can act as a lead or as a source of inspiration. The evaluation of the model pointed out that the model is most applicable to general cases, where tons of interactions happen.

To implement the model, empathy should first be understood very well by a designer and different approaches for integrating empathy in the design should be considered: Empathy as part of design or empathy as a filter. Next to empathy, the way humans solve problems and theories that describe this process are used as a foundation for the design of the model. Where different models and approaches are brought together in a compact model. This model is now theoretically evaluated and proven to make sense in theory. The next step would be a proof of concept.

Besides empathy, the goal also was to figure out how the reasoning of a robot would take shape. A solution to this was formed by exploring the domain of knowledge representation and reasoning. One of the issues in this domain relates to the expressiveness versus the tractability of a representation we use. Where in our case demand is for both. Settling on ontology-based systems and frameworks a broad comparison is made over several aspects of these frameworks. With the help of the findings of Olivares-Alarcos *et al.* [24] we concluded that for this project and the social nature it has, *ORO* or its lightweight version *minimalKB* would be a best first pick to make an empathetic robot. We should finally note that a lot of knowledge that is used in the model is not yet present in these frameworks and should be either added or even be built. This information should also be connected to the word empathy, relating back to empathy in design.

The model this thesis presents and the advice on knowledge representation and reasoning can be quite valuable for future work in this field.

Project

When we look at the general project of making an empathetic robot and also look at the work of J.Kuiken and how the 2 theses merged together, the project seems to have a yet open ending. This theoretical work done by both J.Kuiken and me and the practicalities J.Kuiken already delivered can in the future help in nearing an empathetic robot. Because of the cooperative design approaches we were able to keep the design processes aligned. This cooperation was mainly through the design and use of scenarios. These scenarios did not only help in the design, but they also point out in what domains the models could be applied.

Future work

Following the conclusion of this thesis, there are several ways that this larger project can be continued. First of all, in the merging of the thesis from J.Kuiken and this thesis, a new model appeared, that can be put to the test. After this, the models can be physically worked out and built to prove the workings and most likely redesign and develop an even more complete model. After this, quite likely a more specific application domain should be picked to fully work out this empathetic robot. What will be valuable and reusable in all projects will be the ethical discussion attached in the evaluation chapter. These could act as a foundation for all future ethical analyses'.

7.1 Discussion

7.1.1 Discussion

When we look at the current state of the art of empathetic robots, only pseudo-solutions are presented and used to prove the functionalities of empathy in human-robot interaction. Very little is done in research on how to actually incorporate empathy in a fully autonomous robot: So, how to really make empathy. This thesis has attempted to describe a method of how empathy could be implemented in a robotic system. How this will be used and implemented is kept still quite unclear and can be considered the first step in future work. This work, however, takes an approach yet rarely done in this field and even though it might only facilitate or inspire future work on this topic, I think it is a valuable addition.

The analyses made in this thesis discussing frameworks is quite small compared to all different research in that field and can very well be extended to create a more complete conclusion. Broad surveys both on a specific practice such as the use of ontology's, as well as, on other approaches to use knowledge, should be reconsidered in order to find the most optimal and best solution to the problem. However, empathy can only exist if a lot of other functionalities already exist in a robot, such as speech and other social behavior. In this case, we can very likely conclude that empathy is quite submissive to the system chosen or built. Nonetheless is this project not completely focused on ontology's and could the model possibly also work in a different setting. A general model could therefor quite likely be a useful addition.

7.1.2 Reflection

This project started off with a slightly different goal than currently stated. Originally the goal of the project also entailed making a prototype based on the findings, but soon this appeared to be both out of my scope and likely to be a bit too ambitious. Therefore this project is constrained to making a model and a proper evaluation of applicable techniques.

What did help quite a lot was the extra education/information gained from the book Knowledge Representation and Reasoning by Brachman *et al.* [35]. With the help of this book, quite some concepts became more clear, since little of knowledge representation and reasoning is inside the scope of a creative technologist.

Overall this project gave me a lot of insights into the complexity of robotics.

It allowed me to explore the different aspects of empathy and also created opportunities to take different perspectives and design and develop interesting concepts. Overall I consider this project as a successful scratch on the surface of the future of empathetic robots. Where the technical, theoretical and ethical approaches hopefully are of future use and facilitate the design of safe empathetic robots!

Chapter 8

Acknowledgements

This thesis and accompanying project would not have been possible if it had not been for several people. First of all, I would like to thank Andreas Kamilaris for providing a challenging thesis and guiding me through the not always easy steps in the process. A. Kamilaris also facilitated the cooperation with Jaro Kuiken, which was quite a fruitful cooperation. I'd therefore also like to thank Jaro Kuiken for the pleasant and good communication during this thesis. Because of the time this project exists, during the corona-crisis, quite some things did not go to plan and the execution of the project took a very different road. Due to the situation, a lot less interaction was possible and I'd like to thank all fellow students for tuning in during brainstorm hours in online environments, to keep the blood flowing. At last, all support and input has helped a lot in the process of this thesis and helped me making something I can be proud of.
Stijn E. Slebos

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Appendix A

Scenarios with J.Kuiken

<table>
<tr><td colspan="5">Domain: Elderly care</td></tr>
<tr><td colspan="3">Scenario: Social companion</td><td>Inputs</td><td>Outputs</td></tr>
<tr><td colspan="3">Description: The social robot would have the task of providing social companionship to an elderly; since the loneliness of the elderly is more and more often considered a problem. The robot would need to provide meaningful conversation relating to everyday problems. In this sense, it is important that the robot makes useful connections and can recall previous interaction.</td><td rowspan="2">Real-time conversational inputs, but also knowledge on social interaction, past interaction data</td><td rowspan="2">Speech, conversation, possibly some gesturing</td></tr>
<tr><td>Needed information: Context of the environment, personal information, social skills</td><td>Sensory: Speech, text, computer vision (to some extend)</td><td>Memory: Past interactions, social states, events, up to date events</td></tr>
</table>

Processing:

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Scenarios:

Scenario 1:

Action**:** Breakfast, Elderly enters the room not looking happy
Context**:** Home situation, morning
Sensory**:** John, unhappy
Memory**:** unhappy when slept bad;
Output**:** speech/conversation
Exact output action**:** "Morning John! How are you doing, slept bad?"

<table>
<tr><td colspan="5">Domain: Elderly care</td></tr>
<tr><td colspan="3">Scenario: Memory support</td><td>Inputs</td><td>Outputs</td></tr>
<tr><td colspan="3">Description: The robot would be applicable in scenarios where the elderly are struggling with remembering important tasks or just general important notes. The robot could be the social companion acting as a reminder.</td><td rowspan="2">Real-time conversational inputs, things to remember, past interaction data</td><td rowspan="2">Speech, conversation, some sort of alerting feature in order for the device to grasp the attention.</td></tr>
<tr><td>Needed information: Context of the environment, personal information, social skills, the importance of matters</td><td>Sensory: Speech, text,</td><td>Memory: Past interactions, social states, events, up to date events, personal information, information to remember.</td></tr>
</table>

Processing:

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Scenarios:

Scenario 1:

Action**:** Elderly is just sitting at home, forgetting what the next step was
Context**:** afternoon, call scheduled
Sensory**:** John, dreaming
Memory**:** There's a call scheduled, when john is dreaming he often is forgetting his duties and schedule
Output**:** speech/conversation
Exact output action**:** "Hey John, you have a call to make, remember! Your son is expecting a call in a minute."

<table>
<tr><td colspan="5">Domain: Elderly care</td></tr>
<tr><td colspan="3">Scenario: Rehabilitation assistant</td><td>Inputs</td><td>Outputs</td></tr>
<tr><td colspan="3">Description: In this scenario, the robot has the task as a supportive system in the rehabilitation process. A robot could give feedback on exercises or even be the leading agent in the process: so the robot would monitor and construct the rehabilitation. The robot would tell the subject what exercises to do, maybe by showing a screen or some other output mechanism. It would capture the movements of the subject and incorporate that in the feedback and the general processes of the system</td><td rowspan="2">The social state of the subject as well as visual input on the actual rehabilitation.</td><td rowspan="2">Exampling movements (visual), text/speech on the actions to perform, text actions on feedback, social text: supportive, empathetic.</td></tr>
<tr><td>Needed information: Medical background on rehabilitation, social context, social skills applicable to this domain</td><td>Sensory: Computer vision, speech, text</td><td>Memory: The current state of the process, personal feedback</td></tr>
</table>

Processing:

-
-

Scenarios:
Scenario 1:
Action: Elderly is ready for the rehabilitation, said that het is ready
Context: morning, after breakfast,
Sensory: Jeff, speech recalling he is ready
Memory: Last exercise was yesterday, progress is 45%, health is going up
Output: speech/conversation + screen illustration
Exact output action: "Morning Jeff, how are you feeling, you seem to be progressing well!"
/if feeling well; start with the exercize, else update the exercise to feeling & update progress
…
Sensory2: Jeff recalling that he is doing ok
Output2: "Thats good to hear!, lets start with this exercise to warm up … can you see mee clearly? … "

<table>
<tr><td colspan="3">Domain: Supermarket clerk</td></tr>
<tr><td colspan="3">Scenario: Entrance greeter</td></tr>
<tr><td colspan="3">Description: The robot would be standing at the entrance/exit of the supermarket. It will give normal greetings to customers the robot has not seen before. But whenever a customer the robot has seen before comes in or goes out, it will try to give a more personal greeting message or a shopping tip if there is a discount that might be interesting to that specific customer.</td></tr>
<tr><td>Needed information: Weather info, current discounts</td><td>Sensory: Computer vision, speech</td><td>Memory: Identifying features of customers, past encounters</td></tr>
</table>

Example scenario:
Action: Person enters the shop with facemask and gloves
Context: Corona pandemic going on
Sensory: Tess
Memory: Familiar, person entered without protection last time
Output: speech/conversation
Exact output action: "Hi Tess! I see you're taking the pandemic more seriously already, that's amazing!"

Domain: Supermarket clerk		
Scenario: Item locator		
Description: The robot would be standing in a strategically placed spot in the supermarket. Customers can ask the robot where an item or type of item is located. The robot will give a standard answer to customers it has not encountered before. If the robot recognizes the customer, it will try to give a more personalized answer or even suggest a certain item they have bought before (possibly if that item is on discount).		
Needed information: Store layout, item locations, current discounts	**Sensory:** Hearing, speech, computer vision	**Memory:** Identifying features, past encounters

Example scenario:
Action**:** Person shopping for dinner, asks where the wraps are located
Context**:** Dinnertime, shop mostly empty
Sensory**:** Tess
Memory**:** Familiar
Output 1**:** speech/conversation
Exact output action**:** "Hi Tess! Shopping for dinner a bit late today?"
Tess responds with: "Yes, work took a bit longer than expected unfortunately."
Output 2: speech/conversation
Exact output action: "That's too bad, it happens. The wraps are in aisle 1, at the end on the bottom right!"

Domain: Supermarket clerk		
Scenario: Recipe assistant		
Description: The robot would be situated at the beginning of the supermarket. This way when customers enter the supermarket, they can immediately go to the robot for assistance with picking out a recipe. They could enter what they would like to eat and what ingredients they already have or want to use. The robot would then give a suggestion that is as personalized as possible.		
Needed information: Recipes, store layout, current discounts	**Sensory:** Hearing, speech, computer vision	**Memory:** Identifying features, past encounters

Example scenario:
Action**:** Person asks what they can make with their leftover rice
Context**:** Before dinnertime
Sensory**:** Tess
Memory**:** Familiar, likes spicy curries
Output**:** speech/conversation
Exact output action**:** "You like spicy curries right Tess? Well chicken breasts are on discount right now, so you could make that! Chicken is located next to the cheese section, and you can find a spicy curry mix in aisle 2."

Domain: Supermarket clerk		
Scenario: Shopping assistant		
Description: This would be a more mobile robot, or one that could fit in a shopping cart. (Possibly only less abled) Customers can take the robot with them on their shopping, and assist in any way needed. It could help picking out a recipe, locate items, suggest items and grab items from the shelves if the customer has trouble with this. Meanwhile it would also socially interact with the customer as personally as possible.		
Needed information: Recipes, store layout, item locations, current discounts	**Sensory:** Hearing, speech, computer vision	**Memory:** Identifying features, past encounters

Example scenario:
Action: Person tries to grab eggs that are on the top shelf
Context: Afternoon
Sensory: Janet
Memory: Familiar, has a hard time reaching items on high shelves
Output 1: speech/conversation
Exact output action: “Having trouble reaching for the eggs Janet? Let me grab it for you!”
Output 2: assist shopping
Exact output action: Grab the right brand of eggs from the top shelf and put them in shopping cart

Domain: Supermarket clerk		
Scenario: Stock clerk		
Description: The robot could be put to use in any aisle, stocking products in shelves efficiently. Customers can go up to the robot, and ask it to help them find a certain item. The robot can then relinquish its stocking duties for a while, have a short social interaction with the customer and show them where an item is located.		
Needed information: Store layout, item locations	**Sensory:** Hearing, speech, computer vision	**Memory:** Identifying features, past encounters

Example scenario:
Action: Person asks where the sugar is located
Context: Workday before dinnertime
Sensory: John
Memory: Familiar, usually shops with son Billy
Output 1: speech/conversation
Exact output action: “Hi John! Billy not with you today?
John responds with “Not today, he’s playing with friends until dinner.”
Output 2: speech/conversation
Exact output action: “I see, good for him! The sugar is located in aisle 4, halfway through the aisle on the left bottom shelf.”

<table>
<tr><td colspan="5">Domain: Museum guide</td></tr>
<tr><td colspan="3">Scenario: Front desk/ help</td><td>Inputs</td><td>Outputs</td></tr>
<tr><td colspan="3">Description:
This social robot would funcion on the front/entrance of a museum, where it would be able to help by-passing tourists/ visitors with anything that bothers them: finding the restrooms, having lost a jacket, getting information on the current expositions. This robot would be able to generally help people with their problems, or route them to a place where the solution is likely to be.</td><td rowspan="2">Textual problems a bypasser is bothered with. Topographical questions</td><td rowspan="2">Textual (could be speech) outputs to help the bypasser. Maybe some gesturing feature could facilitate a lot of questions that require movement from the subject to another place.</td></tr>
<tr><td>Needed information:
Environmental data, up to dates on the museums whereabouts.</td><td>Sensory:
Visual, computer vision, speech,</td><td>Memory:
On identical situations, previous solutions, social interactions and recent problems</td></tr>
</table>

Scenarios:
Scenario 1:
Action**:** Someone called jeff lost his kid in the museum
Context**:** afternoon, busy
Sensory**:** Jeff, slight panic
Memory**:** Busy days, kids often go to the kids corner, intercom could be used, people with panic should be calmed.
Output**:** speech/conversation + intercom + screen
Exact output action**:** “Hey Jeff, don’t worry we’ll find him, what's his name? ” + Request camera image of kids corner
/* name = x, first show camera image; If jeff calms down, continue, else request for human assistance
…
Sensory2: Jeff recalling the name of the kid (Bob)
Output2: “Thanks, could you maybe look on my screen and see if bob is in the kids corner?“
/* if kid not there, use intercom. Else tell directions
…
Sensory3: Jeff confirms seeing bob in the kids corner
Output3: “Thats good! You can get there by taking these stairs down and walking straight from there! Just follow the signs!”

<table>
<tr><td colspan="5">Domain: Museum guide</td></tr>
<tr><td colspan="3">Scenario: In-museum clerk</td><td>Inputs</td><td>Outputs</td></tr>
<tr><td colspan="3">Description:
This robot could serve the function of keeping an eye on the museum indoors; while also being able to provide useful and meaningful information on the current expo’s.</td><td rowspan="2">Questions by visitors on the artworks, but also on Topographical questions. Relations and maybe on whereabouts of other bypassers</td><td rowspan="2">Textual, but gestures would also make a lot of sense. Also on the protective side; it should wars visitors to be careful if they come to close for example.</td></tr>
<tr><td>Needed information: Environmental data, information on the current expo and its individual properties</td><td>Sensory: Computer vision, Speech, maybe an interface would also do</td><td>Memory: On relatable facts to the questions asked, past interactions, relating to this person's behavior throughout the museum.</td></tr>
</table>

Scenarios:

Scenario 1:

Action: Someone called john is not understanding the art object in front of him, so asks the clerk

Context: afternoon, quiet,

Sensory: John, interested

Memory: quiet => time to explain, art is by artistX, artistX is parody artist, painting is parodyOf otherpainting

Output: speech/conversation

Exact output action: “John, this is an artwork by artistX, he often tries to mock with other artists in making parodies; maybe look at the painting opposite of it; thats what its based on”

<table>
<tr><td colspan="3">Domain: Airport clerk</td></tr>
<tr><td colspan="3">Scenario: Information desk</td></tr>
<tr><td colspan="3">Description: This robot would be situated behind an information kiosk in the airport. People can come up to the robot as they could to any information kiosk clerk and ask it questions.</td></tr>
<tr><td>Needed information:
Airport layout, general airport information, current flight information</td><td>Sensory:
Listen to the person, speech, computer vision</td><td>Memory:
Past interactions, past solutions</td></tr>
</table>

Example scenario:

Action: Person asks where they can check-in for their flight, one suitcase with them

Context: Holiday

Sensory: Tess

Memory: Familiar, always has two suitcases

Output: speech/conversation

Exact output action: “Hi Tess! Only one suitcase this time? For your flight you can check-in at gate G10, which you will find if you follow the yellow line!”

Domain: Airport clerk		
Scenario: Walkthrough guide		
Description: This robot would be situated at the beginning of the airport. People that have just entered the airport and want some help getting them to where they need to be, can use it as an assistant that will guide them there.		
Needed information: Airport layout, general airport information, current flight information	**Sensory:** Listen to the person, speech, computer vision	**Memory:** Past interactions, past solutions

Example scenario:
Action**:** Person looks stressed, asks where she should check-in for her flight
Context**:** Busy weekend at the start of holiday
Sensory**:** Tess
Memory**:** Familiar, usually calms down when someone helps her
Output**:** speech/conversation
Exact output action**:** “Hi Tess! You look a bit stressed, let me help you. It looks like you have more than enough time to get to your check-in gate, I’ll show you where you have to go!”

Domain: Airport clerk		
Scenario: Store guide		
Description: This robot would be situated in the airport area where all the shops are. People can come up to the robot, tell it what they are looking for, and the robot can guide them to a store that has that product. If that product is not sold in the airport, the robot will give a suggestion of a product based on its past interactions and insight of the person who’s asking.		
Needed information: Airport layout, store locations, product line of all stores	**Sensory:** Listen to the person, speech, computer vision	**Memory:** Past interactions, past solutions

Example scenario:
Action**:** Person comes back from long business trip, asks where the whiskey store is
Context**:** Evening of work day
Sensory**:** John
Memory**:** Familiar, wife likes whiskey and wine
Output**:** speech/conversation
Exact output action**:** “Hi John! Unfortunately this airport closed its whiskey store. But may I suggest the wine store that replaced it, your wife likes that too right? The wine store is to your left here.”

<table>
<tr><td colspan="5">Domain: Education</td></tr>
<tr><td colspan="3">Scenario: Peer (child)</td><td>Inputs</td><td>Outputs</td></tr>
<tr><td colspan="3">Description: The robot would act as a peer of a learning child. In this sense it would be empathetic and follow the track of the child peer-wise. It would learn together with the child and would recall on previous interactions</td><td rowspan="2">Conversation on the to learn matter, communication with the child, struggles and hickups, but also maybe mnemonics.</td><td rowspan="2">Supportive speech, hints and help, maybe provision of mnemonics and such.</td></tr>
<tr><td>Needed information: Educational matters of subject, learning progress</td><td>Sensory: Textbased, speech probably; text</td><td>Memory: Previous interactions, progress, struggles</td></tr>
</table>

** by rereading, I realize there is no specific need of application to education for children, in that sense it could as well be applied to adults or elderly*

Scenarios:
<u>Scenario 1:</u>
Action**:** Kid would be coming home from school and is starting with the homework.
Context**:** afternoon,
Sensory**:** Bob, homework on Maths
Memory**:** Bob has difficulties with Maths, Last progress was chapter 4.6 70%, Bob always forgets to grab some tea or lemonade before he starts.
Output**:** speech/conversation
Exact output action**:** "Hey Bob, ready for Maths today; at what question are we? Don't you forget your lemonade!"

<table>
<tr><td colspan="5">Domain: Education</td></tr>
<tr><td colspan="3">Scenario: Teacher / teaching assistant</td><td>Inputs</td><td>Outputs</td></tr>
<tr><td colspan="3">Description: This would be a more high level task, where the robot actually provides the student some matters. Logically this could be applied in the first learning steps of youngsters. But also improve social behavior.</td><td rowspan="2">Conversational setting where the youngster would provide answers and gets helped by the teacher (robotic agent)</td><td rowspan="2">Explanations, consideration s and feedback.</td></tr>
<tr><td>Needed information: Subject information, psychological knowledge</td><td>Sensory: Speech, computer vision</td><td>Memory: Current state of learning, emotional state of subject</td></tr>
</table>

Scenarios:
<u>Scenario 1:</u>
Action**:** Class of Kids, learning the alphabet
Context**:** midday, much energy
Sensory**:** class full of engaged youngsters, not grasping the letter 'x'
Memory**:** 'x' is a hard letter to understand, middays it is important to not be to complex, break is coming.
Output**:** speech/conversation screen
Exact output action**:** "Okay Kids, lets jsut write 'x' like this a hundred times! And thy ro pronounce it like eggs everytime we write it! After that there is a break!"

<table>
<tr><td colspan="5">Domain: Household</td></tr>
<tr><td colspan="3">Scenario: home assistant - reminder</td><td>Inputs</td><td>Outputs</td></tr>
<tr><td colspan="3">Description:
This home assistant would remind you of your daily tasks and inform you over things relevant to you; some ‘google home’ like devices. It is present as a social go-to and just your personal assistant.</td><td rowspan="2">Conversations about emotional states and needs for the day/week. Certain goals etc.</td><td rowspan="2">Textual/speech feedback on tasks.</td></tr>
<tr><td>Needed information:
Environmental data, social states,</td><td>Sensory:
Speech, maybe vision</td><td>Memory:
Social states (previous), the tasks (though probably linked to some calendar), things you like and current event links</td></tr>
</table>

Scenarios:
Scenario 1:
Action**:** Sally comes home from the fitness and was supposed to do some gardening in the afternoon
Context**:** afternoon, rainy
Sensory**:** Sally, tired
Memory**:** Fitness is tiring, tired people don’t like tasks, gardening is outside, being outside is not nice when it rains.
Output**:** speech/conversation
Exact output action**:** “Afternoon Sally, you were supposed to do some gardening this afternoon, but maybe postpone that to a more sunny day? Then you can also take some rest?”
/* if postponing, find a new spot in the agenda and propose that, else wish good luck.
…
Sensory2: Sally agrees on postponing, but asks for a simpler task
Output2: “Thats good, shall I postpone it to tomorrow afternoon?”
Output3: “Maybe you can then do the laundry now instead of tomorrow?”

<table>
<tr><td colspan="5">Domain: Household</td></tr>
<tr><td colspan="3">Scenario: Personal trainer</td><td>Inputs</td><td>Outputs</td></tr>
<tr><td colspan="3">Description:
The Robot would act as a personal trainer, where it would help you keep in shape and keep track of your training</td><td rowspan="2">Visual input of a workout/ exercise; Emotional and physical state, health issues</td><td rowspan="2">Conversational feedback and tasks for the subject to execute. Advice</td></tr>
<tr><td>Needed information:
What is fit/shape, background on fitness, Health knowledge, maybe music?</td><td>Sensory:
Visual, maybe sound</td><td>Memory:
Previous workouts, errors, hickups and persona’s</td></tr>
</table>

Scenarios:
Scenario 1:
Action**:** Jim tunes in for his afternoon session
Context**:** afternoon, rainy
Sensory**:** Jim, not so energetic
Memory**:** Fitness is tiring, doing sports makes you energetic, sports require energy, Jim is currently doing a ‘core’ buildup, core requires good nutrition.
Output**:** speech/conversation, screen
Exact output action**:** “Have you had a good meal Jim? You will need some energy today”
/* if yes, lets start, else, maybe tune the workout a bit and tip him on better eating next time.
…
Sensory2: Jim confirms having had a good meal, but just a long day
Output2: “Okay, then we can start, are you ready?”

Domain: City centre		
Scenario: Hotspot information		
Description: The robot would be situated at a specific tourist hotspot. It would give tourists who come by more personal answers to questions that might not be on general signs.		
Needed information: General city information, city history information, information about the touristic hotspot	**Sensory:** Hearing, speech, computer vision	**Memory:** Past encounters, past questions and answers to those questions

Example scenario:
Action**:** Person asks the most interesting fact that most people don't know about the hotspot
Context**:** Holiday
Sensory**:** Tess
Memory**:** Familiar, is interested in history
Output**:** speech/conversation
Exact output action**:** "Hi Tess! Something most people don't know about X, is that Y happened to it in YEAR."

Domain: City centre		
Scenario: Tourism tips		
Description: The robot would be situated at the place where tourists usually enter the city the first time, like the rain station. This way tourists who want help to pick out where in the city they should go, could go up to the robot.		
Needed information: General city information, knowledge of touristic hotspots, knowledge of non-hotspot locations	**Sensory:** Hearing, speech, computer vision	**Memory:** Past encounters, past itinerary plans given and reviews of those plans

Example scenario:
Action**:** Persons ask what are some fun things to do in the city
Context**:** Amsterdam group holiday, good weather for a week
Sensory**:** Group of guys in their teens
Memory**:** Not familiar, but teens are usually interested in Red Light district and more
Output**:** speech/conversation
Exact output action**:** "Hi guys! I think you will probably enjoy seeing the Red Light district, the Vondelpark and the clubs in the city center at night. Here is a schedule you could follow!"

<table>
<tr><td colspan="5">Domain: Household</td></tr>
<tr><td colspan="3">Scenario: Housekeeping</td><td>Inputs</td><td>Outputs</td></tr>
<tr><td colspan="3">Description:
This robot would have as task to keep the house clean and tidy. This robot's tasks would entail actions as cleaning, doing the dishes?, laundry, vacuum cleaning. This robot should be able to understand what the 'owner' asks from 'him/her'. The robot can be asked to clean the upstairs floor and can be asked to clean up a room.</td><td rowspan="2">Speech, questions asking for specific in- and outdoor tasks</td><td rowspan="2">Actions concerning housekeeping ; motory movement, tool usage</td></tr>
<tr><td>Needed information: Topographic information on households, classes existing in households</td><td>Sensory: Visual, speech, topographical information; connection to internet for 'owners' whereabouts</td><td>Memory: To-go state, locations of objects, relatable tasks</td></tr>
</table>

**this is ofcourse a bit futuristic now; but I think a lot of people consider something like this the future of robots; so we can maybe see the integration of all those abilities as the end goal (for all robotic development), providing us with subtasks to first focus on*

Scenarios:

<u>Scenario 1:</u>

Action**:** Someone spilled coffee
Context**:** house is quite clean, theres a small social coffee drinking thing going on
Sensory**:** Jeff, Sally, + 3 friends (*when that was still a thing :)*)
Memory**:** Cleaning makes noise, noise is not nice in conversation, coffee is not supposed to be on the floor, it should be cleaned
Output**:** speech/conversation
Exact output action**:** "Hey Jeff, shall I clean that now, it will make some noise?"
/* if yes; clean.exe, else store that it should be cleaned
…
Sensory2: jeff recalls he will do it himself quickly
Memory: cleaning requires a towel
Output2: "Here, I'll bring you a towel"
/* remove that it should be cleaned later

Appendix B

Pseudo approach in proving a model

Inputs
-Vision

```
inShop(ofType Person) = 16
inRange(ofType Person) = 1
ALL WHERE inRange(ofType Person) = TRUE
    Object:Marie
    END
Object:Marie association:carries Object:cart1
Object:Marie isDoing action:Talking
```

-Sound

```
Input clause = association:searchingFor object:Sugar
```

-Spatial sensoring

```
distance(inShop(ofType all)) = (1.2 , 3.6 , 3.7 , 3.8 , ...)
```

-Memory

```
ofType:person association:searchingFor object:Sugar
=(60%)>
ofType:person association:searchingFor object:Sweetener
Not sure about this
```

Problem identification

```
Object:Marie association:searchingFor object:Sugar
Object:Marie association:needs object:sugar
addGoal(Object:Marie association:has object:sugar)
```

Goal

```
Object:Marie association:has object:sugar
```

Solution space - Solution

```
solutionTo association:needs object:x
    = giveObject object:x
     pointTo object:x.place
     leadTo object:x.place
solutionTO association:hasNot object:x
    = giveObject object:x

FOR ALL solutions
If solution:y.available(object:x)
    THEN SELECT solution:y

giveObject.available(object:x)
    IF inRange(object:x)
    AND object:x.weight < maxCarryWeight
    THEN return true

leadTo.available(object:x)
    IF inMoveRange(object:x.position)
    AND inShop(ofType Person) < 30
    AND inStore(object:x)
```

Solution

```
Solution:giveObject{
    Value 1
(some)
    actions:    [1]: moveArmTo(object:x.position)
             [2]: grabObject()
             [3]: moveArmTo(Person)
             [4]: transfer(object:x)

    Goal: object:x.position equals person:y.position
```

```
}

Solution:findAlternative{
(...)
}
```

Knowledge
-Active

```
Object:Marie isA Person
Object:cart1 isA cartObject
```

-Rules

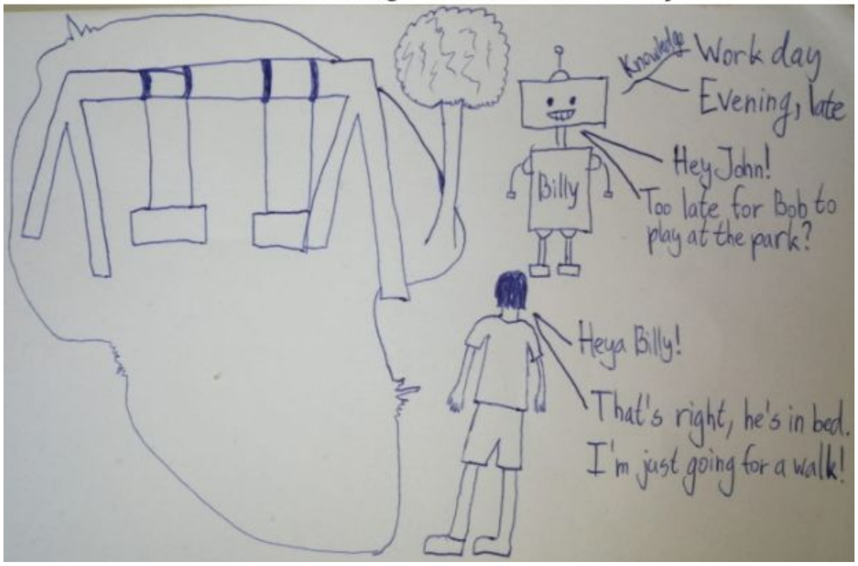
```
Shopper IS A Person association:carries cartObject

IF Person.x isDoing action:Talking
    AND inputClause != Null
    THEN addRule(Person.x inputClause)

IF person:x association:needs object:y
    AND object:y.available() = FALSE
THEN jumpTo solution:findAlternative(object:y)

association:searchingFor => association:hasNot AND association:needs

IF Problem.contains(association.needs OR association.hasNot)
THEN addGoal(problem.person:x has problem.object:y)
```

Appendix C

Iterative design of a model

Robot in a public park

Scenario 1b - Seeing John alone the next day



Processing stage

Input clause:

John enters the park alone

Problem definition

John is alone

John might want to have a conversation

Goal

Have a conversation with John

Environment:

John is alone

It is late

Sun is setting

update states

Subject

John, looks fine, alone

Empathetic module

Alone people want a conversation

It is nice to give some companion

Only try for conversation if john is into it

Update Goal

Comfort john

Solution space:

Have a small chat

Have a large conversation

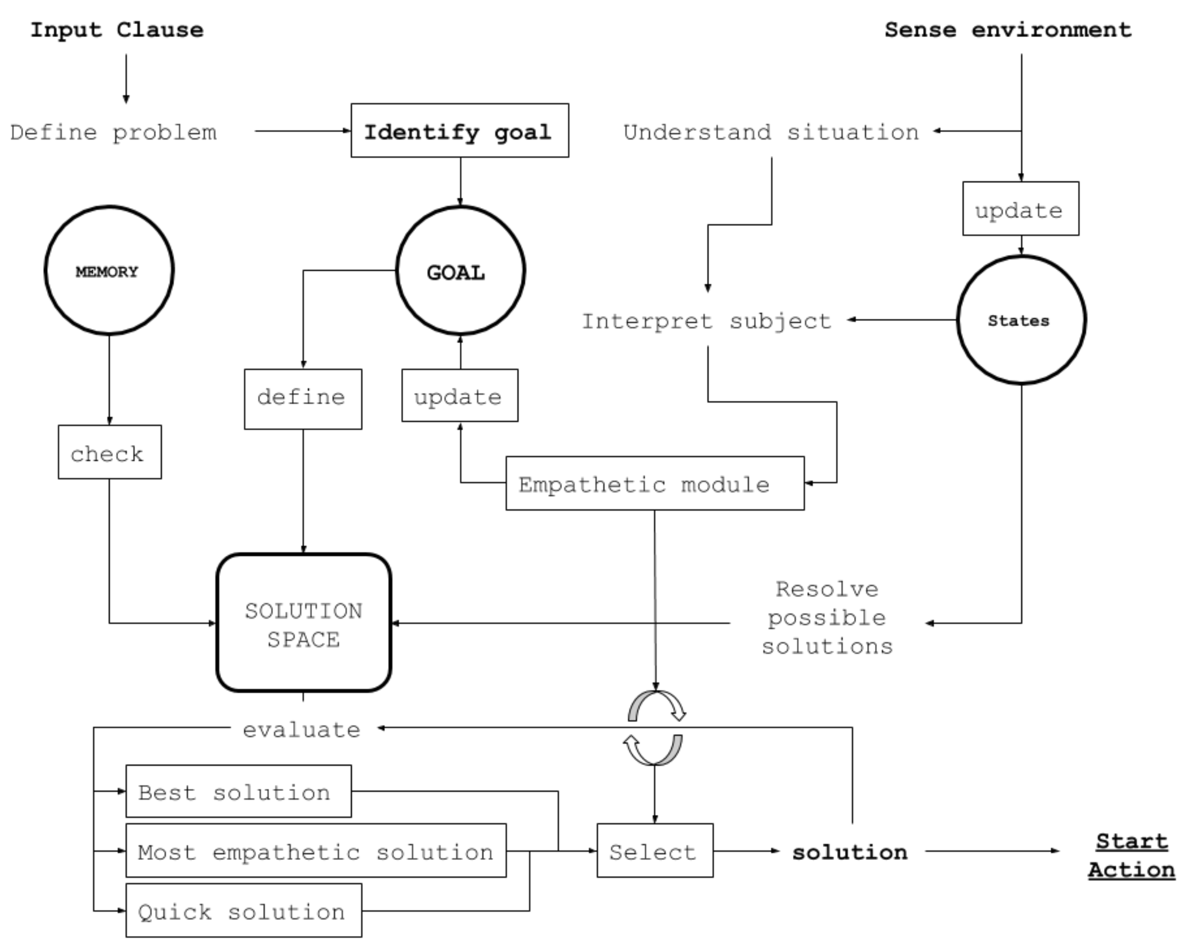
Ask about his whereabouts
Say hi
Check if john is into conversation

Memory:
John is often with billy
Those events occur between 9AM and 16PM

Solution space updated:
Have a small chat about Billy
Have a conversation about billy not being there

Evaluate the solutions
First check if john is into conversation (empathetic decision)

Start action:
Heya John, how is your day?



Action Stage

Start action:

Heya John, how is your day?

Actions:

Wave

Say hi

Turn towards Johns position

Environment

States change in real world

Robot now faces john

John responds:

Hey billy, yea good day!

Re-evaluate solutions with this feedback

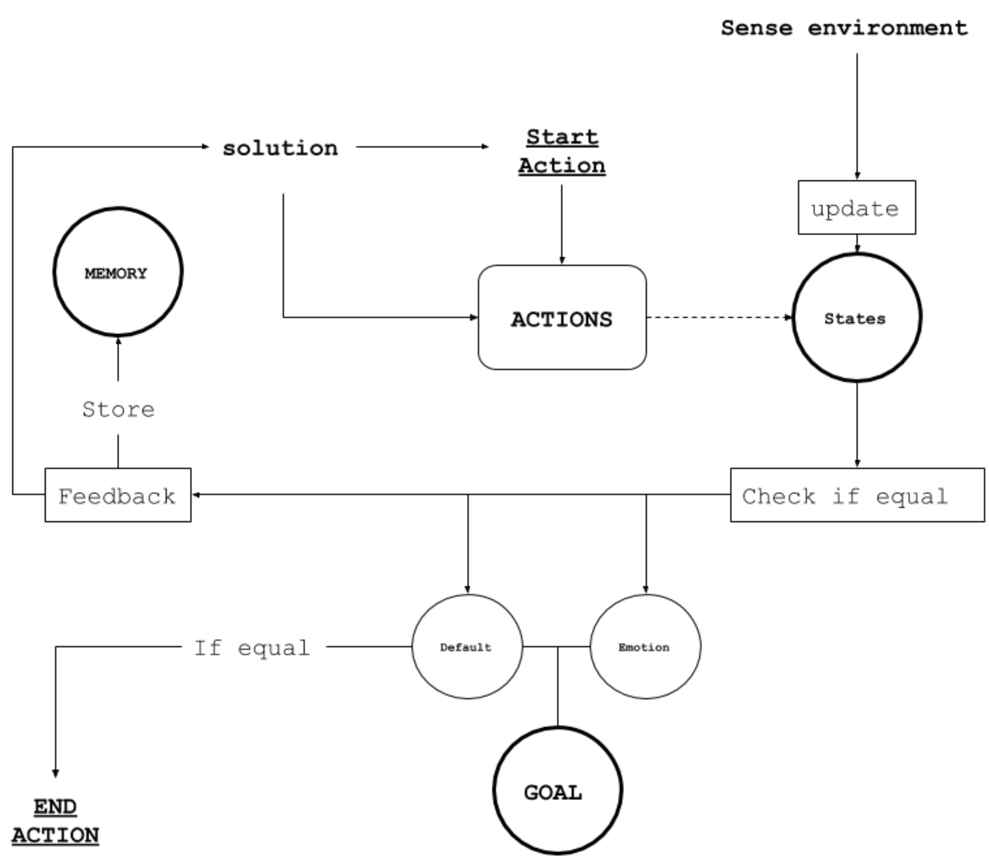
Start conversation about billy

…

If conversation is done

And john is happy

End action



<u>Evaluation</u>
What should the model need to better adapt to this scenario:
Memory could be more connected
Memory and empathetic module should be connected more thoroughly
*Replace **check** memory with **fill***

New Model

<u>Home Bot Ben</u>

Processing stage

Input clause:
Dave enters the room
Problem definition
Dave needs to get through his morning routine
Goal:
Get Dave started

Environment:
It is morning
Sunny day is coming
Calendar says: busy day
Update states*
Situation: Dave has a hard morning, he is tired, but has a long day to come
Empathetic module:
Dave is still quite tired
Dave has a busy day to come
When people are tired in mornings, they need some ease
Take into account dave is tired
Update goal:

Get Dave started while helping him to wake up easily

Solution space:

- Get dave coffee
- Tell about his busy schedule
- Check if he is ready for todays events
- Remind of all things to do in the morning
  - Remind of doing his hair
  - Remind of brushing teeth

Memory -> *Dave needs to get through his morning routine*

- Dave often has coffee in the morning
- He also has his coffee with a simple breakfast
- Busy days have simple breakfast
- Dave likes to work
- When dave is tired, he likes to wake up first

Solution space

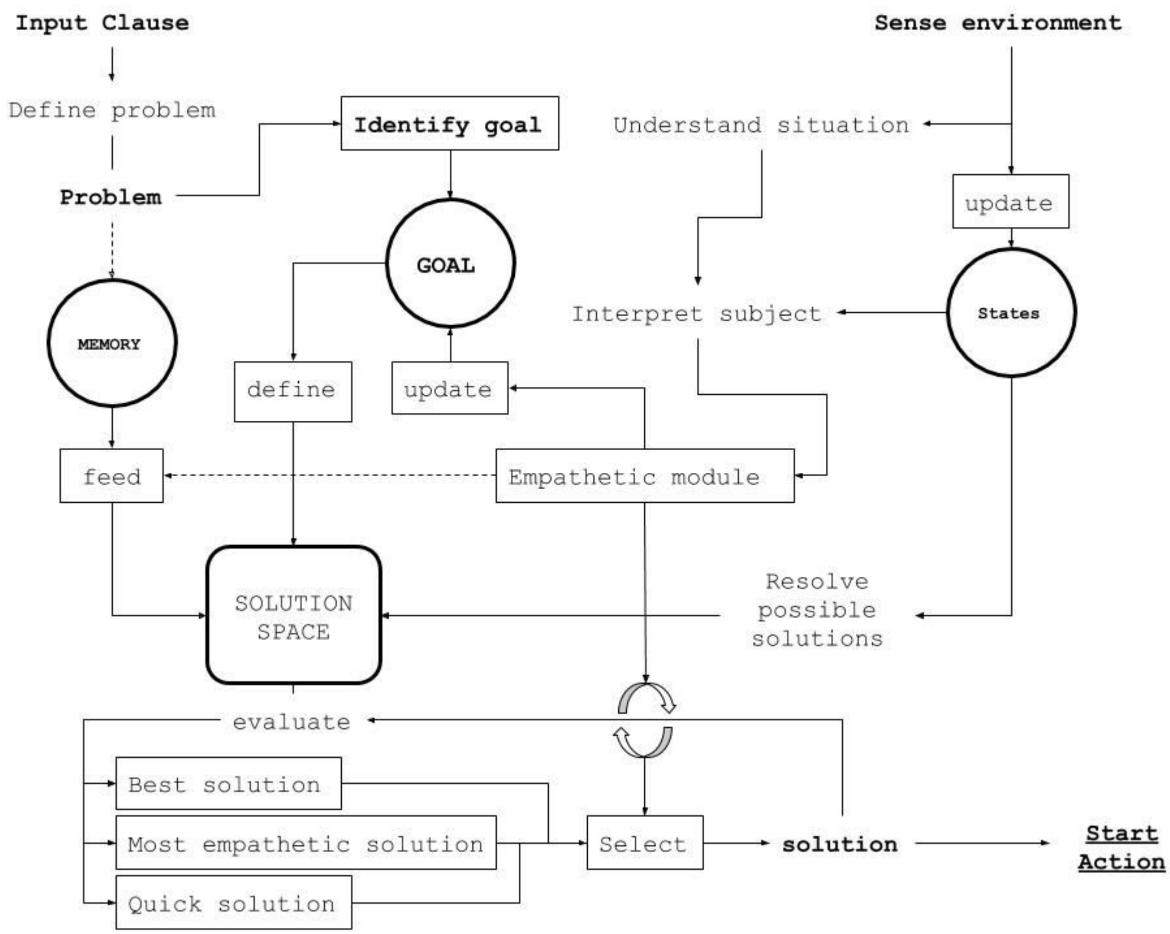
- Get dave coffee for his breakfast
- Let him make a simple breakfast
- First help him wake up

Emapthetic module: ask him

- Best solution, get him coffee with his breakfast
- **Most empathetic solution, ask him if he wants some coffee**
- Quick solution, Get coffee

Start action:

- Morning Dave, you want some coffee?



Action stage:

Start action:

Morning Dave, you want some coffee?

Actions:

Turn to Dave

Output clause

Environment

Dave smiles

Dave responds:

"Yes thats nice, I'll make a quick breakfast"

Interaction:

Want coffee -> yes, + breakfast

Store in memory:

Tired + coffee + breakfast + busy day

Feedback to solution:

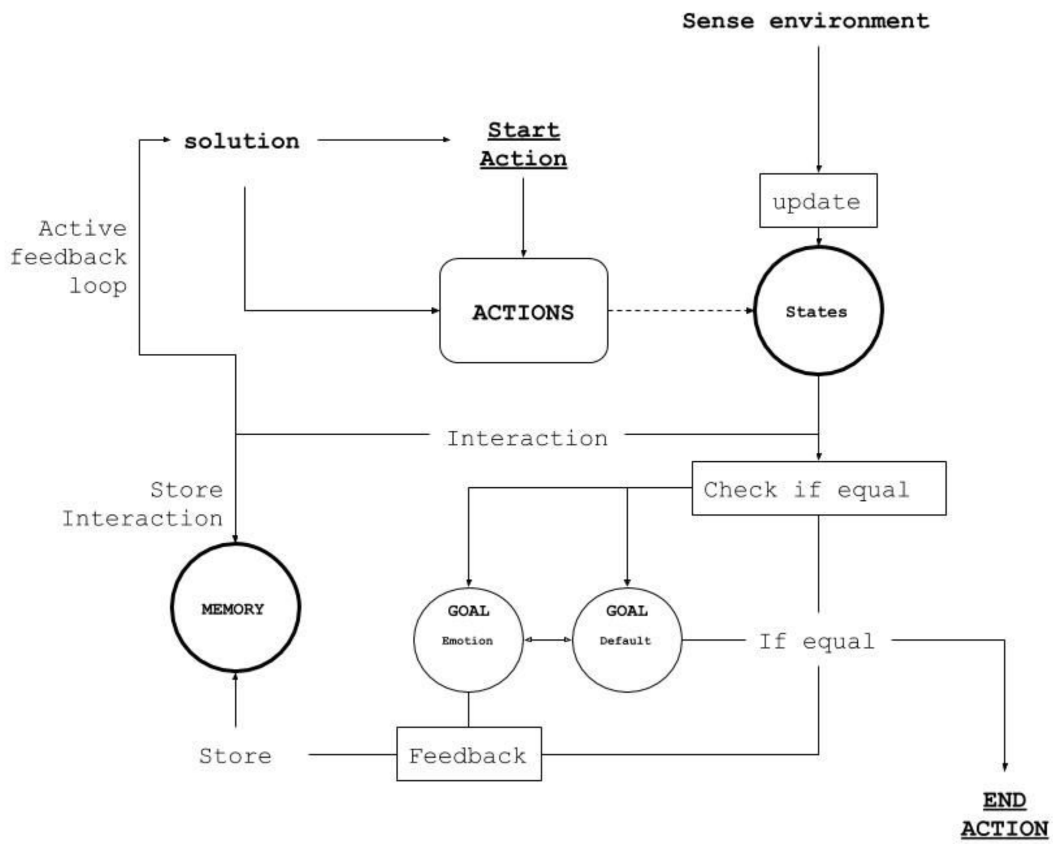
Get dave coffee for his quick breakfast

Actions:

Make coffee / move to coffee machine / activate coffee machine (IOT)

(...)

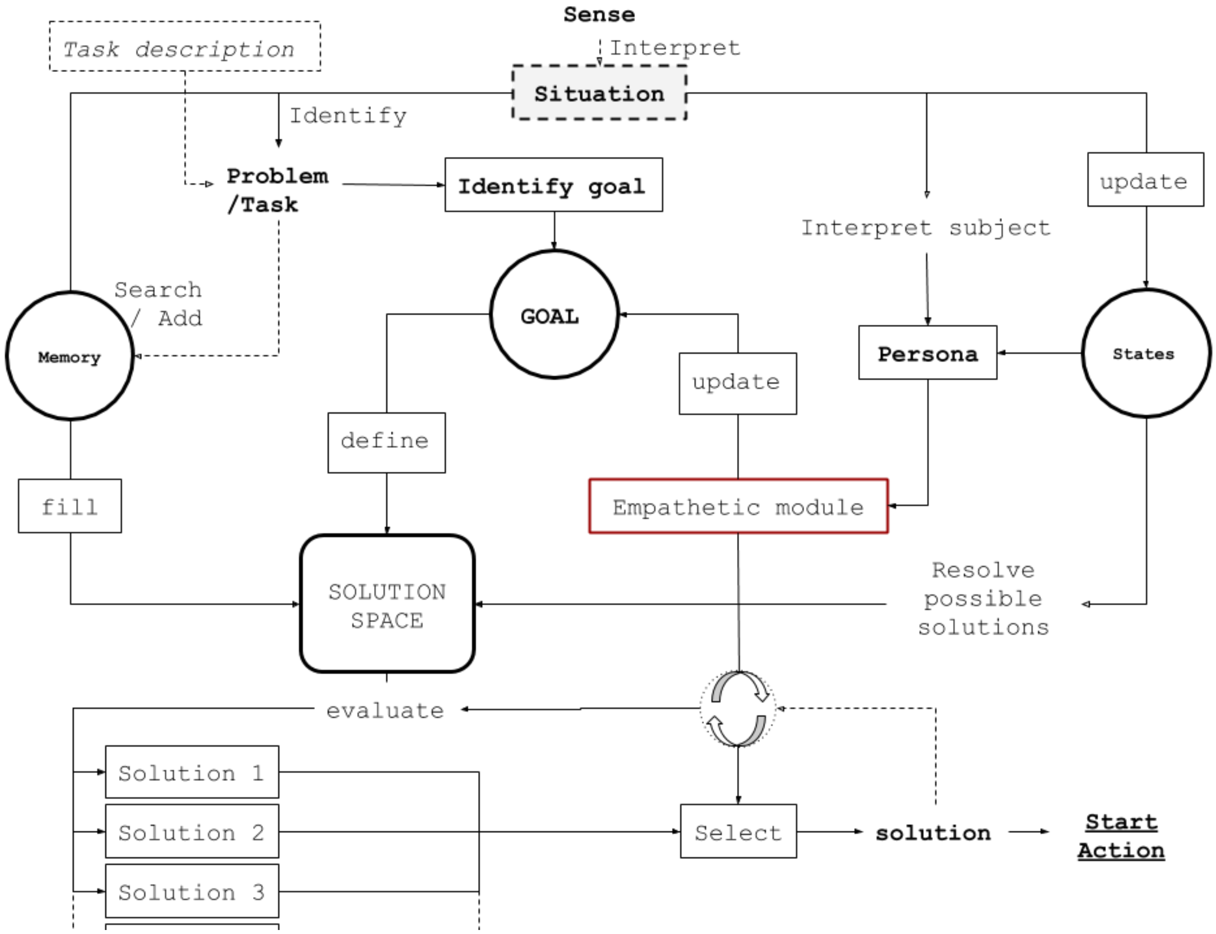
End of the interaction if Dave leaves and is starting his day:
Default goal is equal,
Is Dave also awake and ready?
yes//no/other -> feedback this to memory
Store: Helping Dave with an easy morning, results in Dave being woken up and happy.



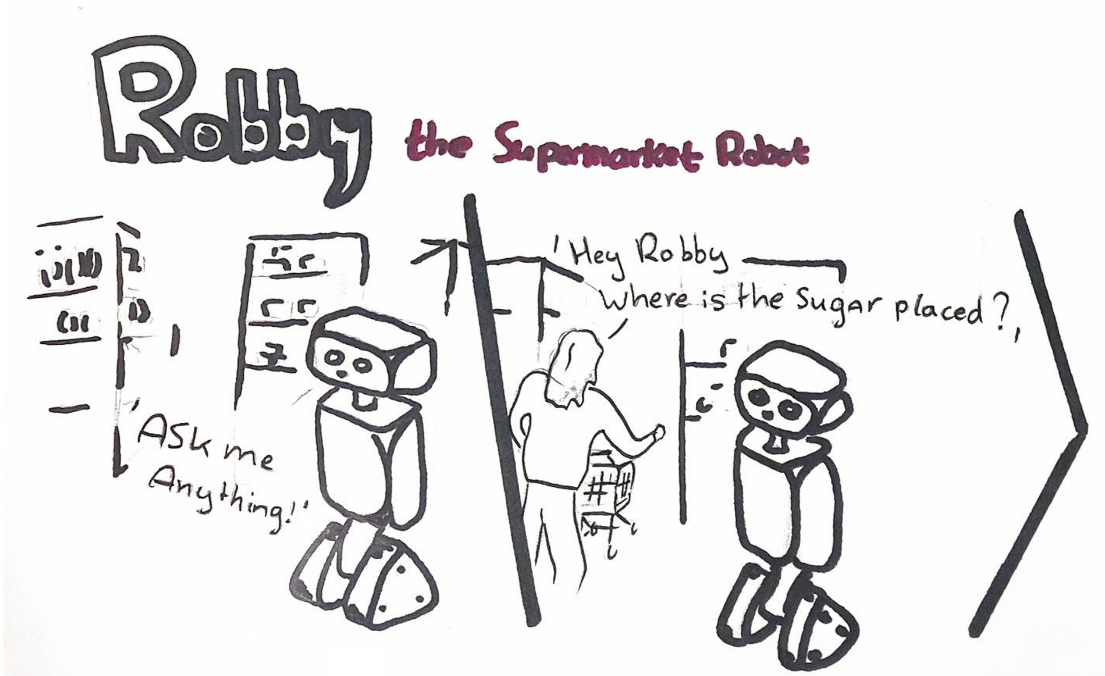
Evaluation

This robot has less focus on problem-goal dynamics, but more on Tasks. This could very well be a very different way of making a robot. This model does not really take into account the active state one is in. Adding these elements however makes up for a way larger system and perhaps this model could be a part of this bigger model. The second part of the model, now makes a lot more sense.

FINAL MODEL



In Scenario:



Robby: Ask me anything!
Marie: Hey Roby, Where is the sugar placed?

Sense / Interpret -> Situation
Person Marie in front of robby
Marie asks: Where is the sugar placed
It is busy in the shop
Update State:
It is busy
Person in front is marie
Update time
It is sunny outside
Currently stands near row 7
Sugar is in row 3
Persona:
<u>Marie:</u>
Does not look happy
Frustrated
Entered 20 minutes ago

Problem/Task:
Marie does not have sugar / can not find sugar
Help people with problems in the supermarket
Goal:
Have Marie knowing where the sugar is placed
Fed to memory: Output is>
Marie forgets things
Marie likes baking
Marie has kids
Marie is here every week
Marie asked for sugar before
Marie also asked for cane sugar once
Marie has had conversations before
Empathetic module:
Marie does not look happy => she has a problem => need a little relieve
Frustration can be helped by easing
Update goal
Have marie knowing where the sugar is placed, and her being relieved

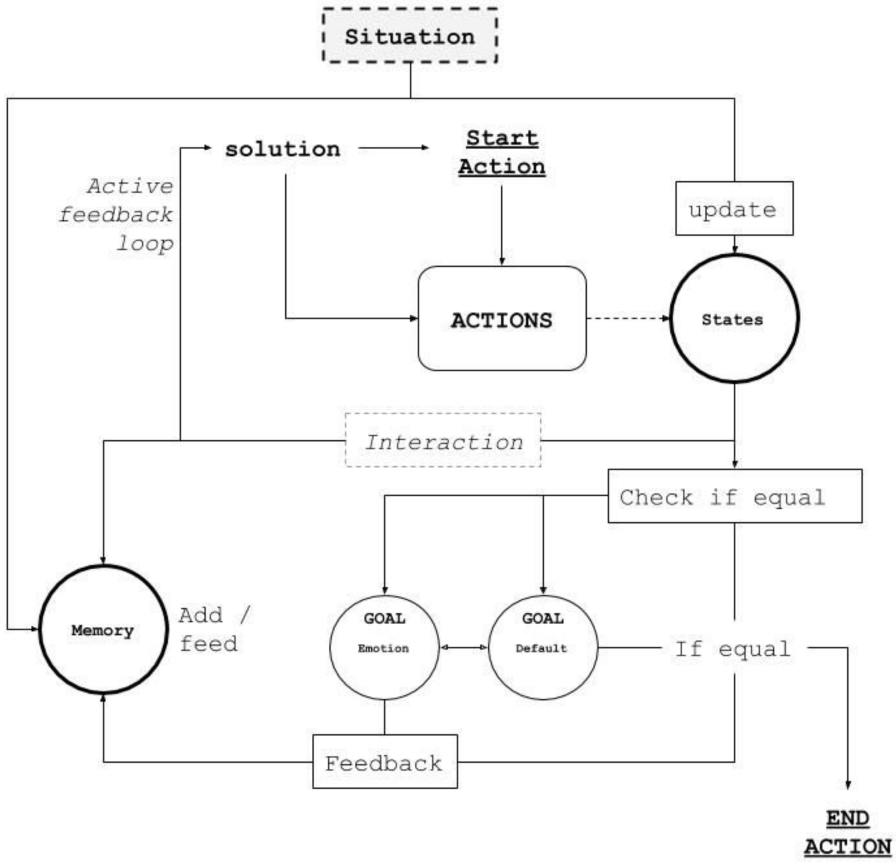
<u>Solution Space</u>
Have a conversation to relieve
Tell where the sugar is placed
~~Show where the sugar is placed~~ -> it is busy
Small chat to ease
-
Ease about forgetting
Ask if she needs cane or white sugar
Ask if she goes baking

(*KB results here in:*
The robot can see that Marie is not so happy.
This could result in changing the goal to also making Marie feel a bit better.
[1] Feeling better can be done conversational
    Being interested
    Asking about her doings
[2] Feeling better can be done by relieving
[2a.] Relieving some stress like
    saying that its not her fault
    Saying taking time is fine

    Or
[2b.] Relieving by allowing for some conversation
    Asking about the day
        -> why it's rough / if its rough
)

Evaluate
Have a conversation = empathetic *if she is into it*
Ask if she needs cane or white sugar = thoughtful + could result in knowing if she wants to talk
Ask if she goes baking = empathetic / interested *if she is into it*
Small chat = slightly empathetic *if she is into it*

Select
Ask if she needs cane or white sugar, = most empathetic, since other options might have negative output if she is not into it



Robby: Hey Marie, do you need white or cane sugar?
Marie: I think I'll be off fine with white sugar

Interaction: I'll be off fine with white sugar -> result is marie needs white sugar , text is nice, she might be in for conversation
Add marie needs white sugar
Feedback to solution and redo previous process

We need to define four things specifically:
How does the Empathetic module work
How does the solution space work
How does the interaction work
How is memory expected to work

Appendix D

Specific Scenario to elaborate on the model

D.1 A specific scenario

In this section the specific scenario of *Robby, the supermarket robot*, is worked out to explore the model in 5.4.

Robby, the super market robot

Question: how do we make Robby empathetic

Empathy: Cover for current emotional state of the subject

Use memory of interactions

Use memory of persona: who is the subject

Robby's functionality:

Help with questions: supermarket related

Locations

Advice

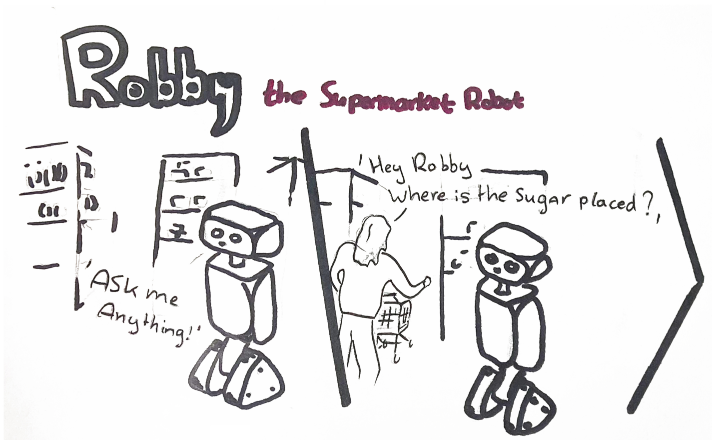


Figure D.1: The sketched scenario: Robby: *"Ask me anything!"* Marie: *Hey Robby, where is the sugar placed?"*

Marie:

- ❏ Comes to the supermarket every week
- ❏ Has kids of +- 10 y/o
- ❏ Likes baking
- ■ Does not look happy
- ■ Is frustrated
- ■ Entered the store 20 minutes ago
- ❏ Earlier times asked for sugar
- ❏ Forgets things every now and then

Robby: / Store:

- ❏ It is afternoon
- ❏ It is busy
- ❏ It is sunny outside
- ❏ Standing near row 7
- ❏ Good music is playing
- ■ Can not move right now -> busy
- ■ Aisles are not fully stocked -> afternoon + busy
- • Sugar is in row 3
    - ❏ Case sugar in row 4
    - ❏ There is still plenty sugar

Knowledge base / information

- Forgetting is frustrating
- Frustration is not nice
- Frustration can be relieved -> is nice
- Reminding should be done with care
- People spend on average 15 minutes in a supermarket
- Searching implies not knowing a location
- Forgetting is a loss of previously known knowledge
- Long searches are frustrating
- People bake with kids
- Baking can relate to pie, cake, cookies, brownies, …
- Baking is fun
- Pie contains sugar, flour, butter, cream
- Bread contains flour, yeast, water, salt
- Cake contains sugar, flour butter
- Sugar is used for baking, coffee, breakfast, …
- Sugar could be: cane sugar, white sugar, powdered sugar, sweeteners
- Afternoon -> people after work
- Weather affects mood: sunny -> more happy, rain -> less happy
- Music improves mood

Output social:

"Hey Marie"
"Do you need cane sugar or white sugar?"
"Forgot it?"
"Planning on baking?" [conversational]

Output not so empathetic:

"Sugar is in row 3!"
"White sugar is in row 3, cane sugar in row 4."

Output more empathetic:

Conversational
"Rough day?"
"How is the day?"
"Forgot it? Don't worry!"
"Take your time"
"We changed the inventory"
"Busy work day?"

EMPATHY
The robot can see that Marie is not so happy.
This could result in changing the goal to also making Marie feel a bit better.
[1] Feeling better can be done conversational
Being interested
Asking about her doings
[2] Feeling better can be done by relieving
[2a.] Relieving some stress like
saying that its not her fault
Saying taking time is fine

Or
[2b.] Relieving by allowing for some conversation
Asking about the day
-> why it's rough / if its rough

Empathy is achieved by adding the social state of the subject to the input as a high value input. Memory is important to strengthen the topics that will be reached with this approach.

EMPATHY
The robot can see that Marie is not so happy.
This could result in changing the goal to also making Marie feel a bit better.
[1] Feeling better can be done conversational
Being interested
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-> why it's rough / if its rough

Frameworks

In frameworks a lot of social interaction is built from different software modules. Empathy could have a separate module. Output clauses should have an empathetic rating: happy +5, stress -2, disgust -3, etc. Check if the output connects to the emotional goal. Empathy should steer decision making.
Steer decision making:
Goal: get Marie sugar.
Empathetic module: Marie does not look happy, so add to the goal: "Relieve Marie in the process"

Goal: get Marie sugar while relieving her.
Relieving can be done conversational: see figure D.2.

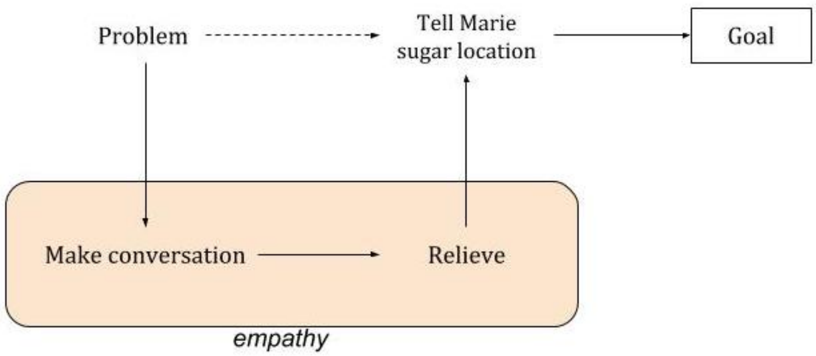

Figure D.2: How empathy changed the solution by updating the goal and reaching two goals