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Requirement Analysis for a Psychoanalytically Inspired Agent Based Social System

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Kurzfassung

Eine künstliche Intelligenz zu erschaffen ist noch immer eine Herausforderung. Es gibt viele Ansätze das menschliche Gehirn und seine Methoden der Entscheidungsfindung nachzubilden. Diese beschränken sich aber oft auf einen Teil der Funktionen des Gehirns. Ein am Institut für Computertechnik entwickeltes Modell nimmt Anleihen an der Psychoanalyse, speziell am zweiten topischen Modell von Sigmund Freud. Dieses Modell repräsentiert einen ganzheitlichen Ansatz mit funktionalen Modulen. Für ein derartiges Modell, welches menschliche Intelligenz simulieren soll, reichen die Methoden der Überprüfung aus dem Bereich des Software Engineering nicht aus. Menschliches Verhalten ist zu einem großen Teil emergent. Und Funktionen, welche nicht in einer Anforderung an das System spezifiziert wurden, sondern aus dem Zusammenspiel entstehen, sind schwer zu überprüfen. Diese Arbeit versucht einige grundlegende Verhaltensweisen des Menschen zu spezifizieren. Darauf aufbauend sollen Testmethoden entwickelt werden, um zu überprüfen, ob dieses Verhalten auftritt, beziehungsweise in welcher Form es sich äußert. Um diese Tests durchführen zu können, werden im praktischen Teil einige Grundlagen dafür geschaffen. Diese beschäftigen sich mit den zugrundeliegenden physikalischen Prinzipien.

Abstract

Creating an artificial intelligence is still a challenge. Many approaches have tried to model the human brain and its methods of decision making. But these are often restricted to fractions of the brain's functions. A model designed at the Institute of Computer Technology is orienting itself towards psychoanalysis, especially the second topic model of Sigmund Freud. This model represents a holistic approach with functional modules. For such a model, which should simulate the human intelligence, methods from the field of software engineering are not sufficient. Human behaviour is for a large part emergent. And functions, which are not specified in a requirement for the system but emerge from the interplay, are hard to verify. This thesis tries to specify some basic human behaviour. Based on them, test methods are to be developed in order to check if and in what form this behaviour occurs. In order to execute these tests, some basics are developed in the practical part. These are concerned with the underlying physical principles.

Acknowledgements

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Table of Contents

Abbreviations

ABM	Agent Based Modelling
AI	Artificial Intelligence
AL, Alife	Artificial Life
API	Application Programming Interface
ARS	Artificial Recognition System
ARS-PA	Artificial Recognition System - Psychoanalysis
ARS-PC	Artificial Recognition System - Perception
BFG	Bubble Family Game
DOM	Document Object Model
ICT	Institute of Computer Technology
MAS	Multi Agent System
MASON	Multi-Agent Simulator Of Neighbourhoods... or Networks... or something... (Webpage definition)
PAIAS	Psychoanalytically Inspired Automation System
PAM	Perceptive Awareness Model
Repast	Recursive Porous Agent Simulation Toolkit
SENSE	Smart Embedded Network of Sensing Entities
SAX	Simple API for XML
SmaKi	Smart Kitchen
WWW	World Wide Web
XML	Extensible Markup Language

1 Introduction

Mankind has gathered vast amounts of information and has gained insight into many fields of our existence. But among the things least understood are we ourselves. Psychology in all its forms is committed to describe, explain, predict, and control how humans are reacting to their environment. But still human behaviour is one of the great mysteries of our time. It is assumed that the reason for this lack of understanding is the complexity of behaviour. Deep down, there may be only a few simple mechanisms and experiences which influence our behaviour. But if they are combined, a complexity arises that makes it hard to foresee how an individual might react in a certain situation. Some people are afraid to speak in public. Some are not. And some even like the thrill. This gives an example how diverse human behaviour can be. And still every single one of these individuals has decision abilities that any form of automation is still decades away from implementing.

Artificial Life systems (AL or Alife) try to implement groups of individuals, which should be able to live and interact in an artificial environment. The behaviour of the individuals is often inspired by real life examples. The goal is to be as close as possible to the one shown by the real life example. Various attempts have been made to achieve this goal. Most of the time, the human brain is taken as the archetype, which inspired the system's decision units. Perceptions, emotions, and a physical or virtual body can be found in many design attempts to model artificial life. The results are still meagre. Almost two decades ago, Brooks [Bro90] already stated that there are a lot of open questions concerning the interaction with the environment. There is still a lot of work to do.

A new Alife system is currently being developed at the Institute of Computer Technology (ICT) of the Technical University of Vienna. This system is called Bubble Family Game (BFG). It is the focus of a large, ambitious project developed by a group of people. This BFG should serve as a test platform for the newly developed decision unit. The decision unit has been designed according to the second topic model of Sigmund Freud. It should be able to make decisions based on a vast amount of input. Therefore it has to filter the incoming data in order to extract the information that is relevant to its goals and decision making. The human mind is good at filtering small fractions of information and making decisions based on it. The underlying intention is to serve as a decision unit for building automation. But before this implementation of the human brain can be used for building automation, it has to be tested if its abilities are similar to a human being using a virtual environment. The main actors in the BFG are called Bubbles. A virtual body is provided for them, which has demands the decision unit has to satisfy. Other Bubbles exist for interaction and cooperation. Different requirements in the environment will

make interaction necessary. These requirements should make humanoid behaviour necessary if the Bubbles want to survive and prosper.

But how can behaviour, even that of virtual beings, be tested? It is desired that the behaviour in question is similar to that of humans. The underlying decision unit is a software project. But typical test methods used in software engineering are hardly applicable for behaviour. Software engineering tests assume that for a given input one specific output will emerge. But as mentioned above this is not how behaviour works. In one specific situation various reactions of the individual can occur. Some might be more likely and appropriate than others, but in the end a definite prediction is not possible.

Nevertheless this thesis tries to define tests for the behaviour of virtual beings. It is clear that only a small fraction of possible behaviour can be described in this thesis. A few behaviour patterns, which are either very fundamental for human behaviour or are in other ways interesting, were picked. These behaviours are:

Dynamic Group Finding The tendency of humans to form groups. This has many advantages for the individuals like help from others or exchange of goods.

Hierarchy Every natural group tends to establish a hierarchy. This hierarchy determines who has privileges and who does not have them.

Specialisation Some individuals of a group often have abilities that make them better at something than others. They tend to specialise in this ability and do this on a regular basis. One of the specialisations occurring in all groups is being the leader of this group.

Ability to Work in a Team If individuals come together to work as a team, the team members have to be sure that it is for the benefit of all. No member should exploit the effort of the other team members.

Adequate Emotional Reaction Emotions can help to judge and prepare for a situation. But if the wrong emotions are shown, this can be counterproductive or fatal.

Love A binding between two individuals. Various factors can influence positive feelings towards another individual.

Aggression The intention to harm another individual. Different causes like frustration or pain can lead to aggressive behaviour.

Stress An individual can prepare physically and mentally for a threat or a dangerous situation. If this threat persists for too long, the individual suffers from stress and its symptoms.

Behaviour during Conflict of Goals An individual can solve a conflict either with rationality or with emotional decisions. Emotional decisions can be influenced by various factors.

Reciprocity A basis for interaction between individuals is the certainty that favours done to others will be returned someday.

False Expectations Even a clear understanding of the cause-and-effect-principle can lead to false interpretations and expectations of events.

Consistency If an individual learns something, it will tend to behave according to its experiences. This experience will lead to consistent behaviour in seeking pleasure and avoiding pain.

Of course such a selection can only be subjective. But from the standpoint of a psychological layman, they seemed interesting and useful. Behaviours like love, aggression, or group finding are basic human behaviour. Especially from a psychoanalytic point of view.

For each of these behaviour patterns, typical triggers and reactions can be determined. This gives a description of a typical behaviour scenario. The next step is the decomposition into the parts of the behaviour. The causes and the reactions are identified and categorised. If the typical behaviour sequence is determined, the requirements of the environment can be described. Since behaviour is a reaction to a stimulus, the world has to contain objects and events which provide these stimuli. Also the necessary abilities of the agents have to be identified. The agents have to have the ability to react to a situation according to their decisions. Finally the test cases can be designed. A situation is presented to the agents that they have to react to. This situation consists of the aforementioned objects and events. The agent can now make decisions and act them out through his abilities. The test case would be a success if the Bubble chooses a reaction that can be expected from a human being.

The process from describing the behaviour patterns to the definition of the test cases will be the focus of this work. Even if this work aims for a general applicability, the focus is on the new decision unit. This decision unit will be briefly introduced. However, the actual development of the decision unit is not to be discussed in this thesis. The contribution to the development of the decision unit will be only the provision of the test cases. Not the development of the decision unit itself.

As mentioned, the decision unit of the Bubbles is derived from Freud's second topic model. This means that psychoanalysis had a major influence on the structure of the Bubble's mind. But to test the Bubbles with psychoanalytical methods might prove to be hard if not impossible. The aim of this thesis is to provide test methods, which allow to test the Bubble's behaviour without looking into them. The internal state of the Bubbles will not be the concern for these tests. The only way to determine if the behaviour in question is occurring is through observation. Even if this method reminds of behaviourism, it is a practical way to determine if behaviour similar to that of humans occurs. And such behaviour is the goal of the project, which builds the decision unit.

The simulation was migrated to a new simulation framework recently. The used framework for the implementation is called MASON (Multi-Agent Simulator Of Neighbourhoods). It is a simulation framework for networks, agents, neighbourhoods, and others. The new decision unit is still under construction. Therefore the implementation of the test cases and the analysis of the decision unit is not possible at the time this thesis is written. As a result, the practical part of this thesis lays the groundwork for some of these cases.

The already existing physics engine of the new framework is to be extended. This will provide the environment with different surfaces that have different frictions. Moving on these surfaces will cause the Bubbles varying efforts depending on the surface. The implementation of surfaces is done with the aim to implement test cases like the decision making during goal conflicts of the Bubbles. An example would be the test if Bubbles risk a high effort by moving over difficult terrain in order to gain something, even if the reward is not worth the effort.

The theoretical part of this thesis shall provide the project group with the means to test the described behaviour of agents similar to humans. But anyone else with a similar task should profit from this thesis as well. The practical section provides part of the groundwork for testing these behaviours in a specific context. This will be a first step to test if the Bubbles really show behaviour comparable to humans.

2 State of the Art

This diploma thesis is intended to be part of a larger project. Therefore an introduction to this project and its theoretical background is given in this chapter. First the Artificial Recognition System project (ARS), with its sub projects ARS-PC (Perception) and ARS-PA (Psychoanalysis), is described in Section 2.1. In Section 2.2 the history of the ARS-project is outlined shortly. In this part the reasons for the development of the current model are outlined. Some related projects are also described. The first decision unit based on psychoanalysis and the one currently being developed are described in Section 2.3. In Section 2.4 the topic of Artificial Life (AL) is introduced. These concepts are used in the ARS-project to provide a testing environment for the models. In the last section a short introduction of frameworks for agent based systems is given.

2.1 Artificial Recognition System

The ARS project [1] was founded at the Institute of Computer Technology (ICT) of the Technical University of Vienna [2]. The project is an interdisciplinary research project, which combines many different fields of expertise. Included research areas are computer technology, psychology and psychoanalysis, neuroscience, architecture, and automation. Therefore for this project, different institutions and individuals work in collaboration. First the goals and motivation of the ARS project are introduced and introductions to ARS-PC and ARS-PA are given.

The ARS-project tries to build an artificial system that is able to perceive and process information. The ideal for this attempt is the human brain. Its ability to perceive information from the environment, filter the important information, make decisions on these and prior informations, and then act on it is still unrivalled. The ARS-PC team is trying to create a system that is able to perceive sensory input and compare it to previous information. The ARS-PA team tries to use Freud's second topic model (Id, Ego, Super-Ego) as a decision unit for automation. Other projects of ARS are SENSE (Smart Embedded Network of Sensing Entities), which is concerned with embedded sensors. PAIAS (Psychoanalytically Inspired Automation System) tries to implement the model first into agents and later also into robots or building automation systems. The predecessor of ARS was the SmartKitchen, which tried to automate kitchens to make them saver, more energy efficient, and overall more friendly to use.

2.1.1 Motivation

During the last years, it became obvious that the growing numbers of sensors and actuators in automation are used. But automation methods used until now are not able to manage them efficiently anymore. The sensors produce a vast amount of information every second. Most of this information is not relevant in any way. Only a small part of this information is relevant and needed for further calculations. This started a search for new, more efficient methods in information processing. A new model is required that is able to extract the needed important information from the sensors in order to recognize a pattern. This pattern is used as basis for the calculation of a decision. Then this decision can be carried out via the actuators. A more detailed motivation can be found in [PDHP07].

The whole field is still basic research. Various problems and questions are still unanswered. We do not know if our understandings of the human brain are sufficient enough to implement it in a computer system. It is questionable if the functions of the brain can be transformed into computer programs at all. But maybe it is possible and our knowledge is sufficient enough. This does not necessarily mean we have the right model from which the desired behaviour can emerge. But as Edison needed many trials to create a light bulb, it has to be tried to find out if it works. And if it does not, there is at least something to learn from it.

2.1.2 ARS-PC (Perception)

The ARS-PC (Perception) tries to use theories of perception from living beings and integrate them into a model for computational perception. The perception of living beings especially of humans is the "state of the art" in this field. This is because of more than one factor. One factor is its filter mechanism. Every second a vast amount of sensory input, visual, auditory, tactile (i.e touching), olfactory and gustatory, is transmitted from a person's sensors (eyes, ears, skin) to its brain. The brain is now able to recognize the mostly small part of important information from this input. This small part is processed and the rest is discarded. Another factor is the ability of the brain to assemble the information gained from the sensors and recognise objects, persons and scenarios.

Humans do not have to think about these functions of the brain. But in all the attempts to implement similar functions into algorithms the resulting program performs rather poorly in comparison to the human brain. Today's feedback control theory is only able to process a small number of input sensors. These methods are in no way capable of processing the input from tens of thousands of sensors which become more and more common in building automation.

The new model uses symbols to represent what the system perceived. These symbols are arranged in a hierarchical pattern. Symbols on a higher level are composed of various symbols from the level below. The higher up in the hierarchy the more information is combined in the symbol. The information on higher levels is also integrated with information stored in the memory of the system [Vel08].

The system should now be able to use the redundant, diverse data to build a representation of the world which contains all necessary information. Until recently the approach in build automation was a different one. The goal was to keep the redundancy of the input low. This had two reasons. On the one hand sensors were expensive. So low redundancy was an economic factor. On the other hand, lack in processing ability of the system made it hard, if not impossible, to process a

large amount of input. On the downside the failure of one sensor could affect the efficiency of the whole system. But since the price of sensors is estimated to fall in the near future, the increased use of cost efficient sensors is predicted as described in [DLP+06].

The goal of the project is to create a system which models the human perception. This will be used in order to create a representation of the monitored environment. This representation should contain only information relevant to the assigned task. For example the system can be assigned to track a person. In this case it would focus on where the person is located in the building and not what the person is doing.

The information processed is taken from two sources. First the information from the outer world is taken to determine what is going on in the environment. Second the stored knowledge is used to interpret the perceived information. The result is a representation of the real world. The selection of the sensors should tend to a large amount of sensors, which observe only a small part of the world and its state. Only a small amount of complex sensors, which have advanced observing abilities like cameras, should be applied. This information is used to build the consistent holistic representation from small pieces of information. More information about the ARS-PC project can be found for example in [Vel08] or in [Bur07].

2.1.3 ARS-PA (Psychoanalysis)

In the previous section a model for interpreting and integrating sensory input with stored information is described. This perceived information is usually the basis for the calculation of an adequate response which is realised via some actuators. These systems are now able to autonomously decide what an appropriate action would be in the situation at hand. The research in autonomous decision units is not only interesting for building automation but also in every field, where an automated entity has to make decisions on its own.

To be able to make decisions on its own the system has to be able to experience the world. The current situation has to be evaluated and possible actions have to be defined. Based on the expected consequences the system acts out a decision in the world. After the decision was carried out the system is expecting to get a feedback what result this action has caused. This characteristic of a system to be able to perceive its environment and to interact with it is called embodiment [Bro91].

In search for an evaluation method for decision making, emotions became more and more interesting for the field of artificial intelligence. Despite the fact that many different definitions are given, what is to be regarded as emotion and how to classify them (compare for example [EK03, p.493-494] and [ST02, p.114-132]) we all have an intuitive understanding of what emotions are. Psychologists tried to exclude the effect of emotions on cognition to simplify their research. But in the last two decades emotions got accepted as a crucial part of cognition [EK03, p.489]. Psychologists and cognitive scientists still try to fully grasp the importance and effects of emotions. Meanwhile scientists in the fields of artificial intelligence and robotics have tried first implementations of emotional architectures for decision units. But the lack in understanding the mechanisms of emotions make it hard for system designers to define standards and criteria for system evaluation. But new understandings in psychology can improve the design of emotional systems. In turn the findings in designing emotional systems can help cognitive scientists to help finding a better understanding of the workings of the mind in general and the influence of emotions in specific.

The goals of the ARS-PA project are now on the one hand, as mentioned above, to better understand the functional roles of emotions and other psychic functions. On the other hand a cognitive system should be enhanced with emotions in order to improve its abilities in making decisions.

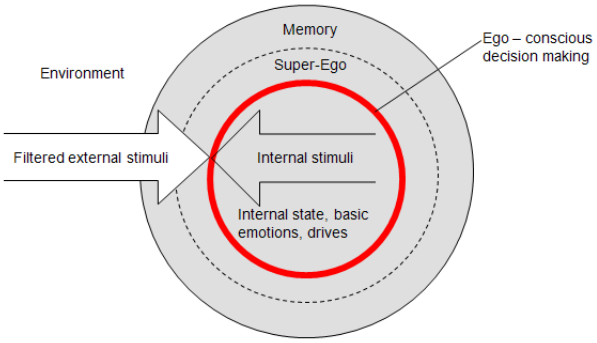

Figure 2.1: A model for perception and evaluation based on emotions as depicted in [Roe07].

Based on these considerations the project group was searching for a model that fulfilled the requirements mentioned above. The theoretical model can be seen in Figure 2.1. A hierarchy of functions is assumed by the model. On a low level of emotional processing basic functions like reflexes and drives are assumed. On a higher level complex emotions like shame, pride or love are positioned. The emotional evaluation makes it necessary to couple the perception of the external world with the perceptions of the internal state. The reactions to stimuli are also processed on different levels. On the lowest level reside reactive processing, which does not process much of the information but gives a "hard wired" response. Above that automated reactions which were learned and trained over some time are located. On top of the model the system is able to reflect on the situation at hand and take various factors into account for processing a decision.

The model is implemented in a stepwise manner. Single components are implemented are supposed to be as simple as possible. The implementation is not a simple bottom-up approach. Higher cognitive functions should be integrated if it is useful and possible. More information about the ARS-PA project can be found for example in [DLP+06] or in [DFZB08, p.47-64].

2.2 Projects and History

In the past various projects have been initiated at the ICT in the context of ARS. The intent of this section is to give a quick overview over the past and present projects and works that have provided the ground work for this thesis. The initial idea was to compare the concepts in building automation to those found in nature [PDHP07]. The function of field bus systems was compared to a nervous system. This analogy triggered the research for systems inspired by the findings of psychology, psychoanalysis and pedagogics. The SmartKitchen was the first attempt to implement some of these principles.

2.2.1 SmartKitchen

The SmartKitchen (SmaKi, [3]), described in [SRT00], [Tam03] and [Rus03], was an attempt to build a control system for a kitchen. This system should make working in this kitchen saver and

more user friendly but also more energy efficient. For the implementation, one of the kitchens of the ICT was used. Some sensors were added to provide the information about what is going on in the kitchen. This information is sent to a server located in the kitchen for further processing.

The idea behind SmaKi was the Perceptive Awareness Model (PAM) as described in [Tam03]. It was intended to build a layered model that acted preventive rather than reactive. The state of the art up till then were purely reactive systems, which only react on input but disregard the surrounding environment completely. In contrast, human behaviour takes into account its surrounding and tries to anticipate the effects of its behaviour. Studies in neuroscience, psychology, biology and other disciplines showed that human behaviour is based on three basic principles:

- perception of a situation
- recognition of the situation
- a decision which takes into account possible side effects

The developed control system should now be able to perceive redundant situational information through its sensors. This information is now merged into a context represented by so called "symbols". Based on these symbols certain actions can be taken through actuators. For example the window could be opened if the air was bad, or the stove could be turned of if not used.

2.2.2 SENSE

The SENSE project (Smart Embedded Network of Sensing Entities) introduced in [PF07] develops tools, methods and a test platform for the design, implementation and operation of smart adaptive wireless networks of embedded sensing components. This network is an ambient intelligent system. It adapts to its environment, creates ad-hoc networks of heterogeneous components and delivers reliable information to its component sensors and the user. The cooperation of the sensors intends to build and maintain a coherent global view based on local information. New nodes automatically calibrate themselves and share knowledge with neighbours. The local information processing and sharing makes the network scalable. The network is also self organising based on the physical placement of the nodes. The test application will be a platform for a civil security monitoring system, consisting of cameras and microphones. As test field an airport was selected to yield real data and goals from a realistic test environment.

2.2.3 PAIAS

The goal of the PAIAS (Psychoanalytically Inspired Automation System) project is to design a system based on the example of the human mind. This decision unit should be able to take sensor input and form a representation of the environment. It should make decisions based on what the system believes the world looks like and what it wants to do in it, to reach its goals. This situation awareness should result in reactions of the decision unit. The most important decision in the beginning of this project was to determine what this the model behind this system should be. The ideal it would be measured against is the human brain. The problem is that various theories about the workings of the brain exist. Some of these even contradict each other.

Eventually, the second topic model of Sigmund Freud was chosen. It provides a holistic functional model, which was considered promising for the task.

In this project a deeper understanding of the concepts is desired. Especially with regard to creating a technical model from the psychoanalytical model. This requires, among other things, a clear specification of terms and functional entities.

The first step for the implemented system would be to superimpose it onto a couple of virtual agents within a simulated environment (see Section 2.4). These agents are equipped with sensors and actuators. The agents can sense on the one hand the external environment in which they exist. On the other hand they can sense their inner state and feel their needs. Through the actuators they are able to manipulate their environment in order to reach their goal, which would be the satisfaction of the needs. The task of the model is to combine the gathered information. This is used to make a decision which results in an action that has the intent to lower the needs of the agent.

If this model proves useful in a simulated environment, other applications might follow. Possible fields might be robotics, web agents and as mentioned above building automation, which is the initial goal of the ARS project.

This thesis will be mainly concerned with the PAIAS project of ARS. The application of the model for agents in a simulated environment is the centre of the discussion. In this thesis verification of the model's modules will be discussed. The working of the modules and the emerging phenomena are of interest and how these can be tested.

2.3 Psychoanalytically Inspired Decision Making Models

In this section the two models of a decision unit developed by the ARS project team are introduced. The first one is described in Section 2.3.1. The second top-down model presented in Section 2.3.2.

2.3.1 ARS-PA Model

Various models would be a candidate for a representation of the human psyche. From the psychological perspective schools like behaviourism could have been a choice as well as already existing agent architectures like for example BDI-agents. But the model should not describes the behaviour as a whole. Instead the project team wanted a model which could easily be broken down into separate modules with different functions. Each of these functions and their interaction should be describable separately. The neuro-psychoanalytical model is the most complete functional model of the human brain in comparison to other models and theories [DFZB08, p.30-33]. This was the main reason for choosing the neuro-psychoanalytical model for implementation at the ICT.

The first technical model of the brain developed at the ARS-PA project was heavily influenced by the new trend to integrate neurological findings with psychoanalysis. Findings in this area were for example depicted in [ST02] which in turn was heavily influenced by Jaak Panksepp and Antonio Damasio. The integration of these disciplines is rather uncommon because of their opposite approach. Neuroscience takes a "bottom-up"-approach that starts at the neuroanatomy and

neurophysiology and tries from this basis to get to a model of psychic functions. Psychoanalysis takes the "top-down"-approach. The behaviour of an individual is observed and the underlying brain functions are tried to be determined.

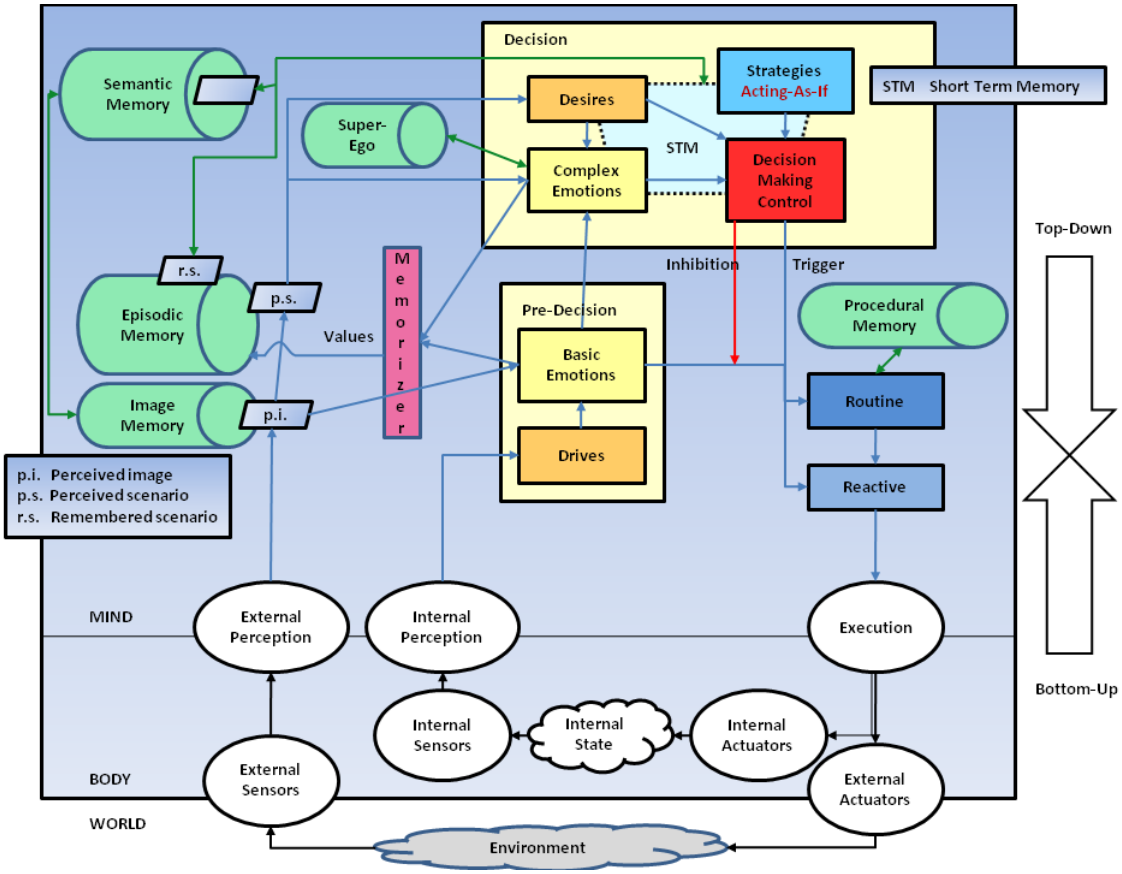

Figure 2.2: The first ARS-PA model as depicted in [DLP+06].

The model which is depicted in Figure 2.2 orients itself on Freud's second topographical model with its agencies Ego, Id and Super-Ego. The problem in constructing the model was staying close to the concepts of the original literature of Freud. Also the transformation of some psychoanalytical terms into a technical model were a non-trivial task.

As explained in [DLP+06] when applying the model there are three basic components: 1. *Basic*[1] and *Complex Emotions*, 2. *Ego*, *Id* and *Super-Ego*, 3. unconsciousness, pre-consciousness and consciousness. These components try to solve basic tasks early in the decision process. *Id*, *Super-Ego* and *basic emotions* are needed for the self-preservation of the individual. *Ego*, *Super-Ego* and *Basic Emotions* are needed for social abilities. The three stages of consciousness represent the ego's ability to reflect why it has taken certain actions.

The *Ego* is the interface which mediates between the demands of the inner world, the needs of the body, and the outer world, the state and changing of the environment, and the perception of both. It mediates between the requirements of the environment, the *Id*, the *Super-Ego* and the emotions resulting from the prior. Also the *Ego* is responsible for control of the motor functions.

[1] In this and the next section all modules are written in *italic*.

As explained in [PDHP07] all perceptions, internal and external, are first condensed. The sensor input is coded into so-called Microsymbols. Multiple Microsymbols which represent the same fact in the world but originate at different sensors are combined into a snapshot symbol. They are a first association between the Microsymbols. These are combined into representation symbols, which are few and seldom created or destroyed. On this level the current state of the world and the recent history is represented, which is used for applications. These representations are used to identify scenarios, which have emotions attached to them in order to evaluate them.

There are basically two kinds of memory as explained in [ST02, p.150-167]. The short term memory consists of the most recent events and has limited capacity. It usually contains the events of the last few seconds. The long term memory holds entries over a lifetime. It is able to store entries of different kinds. There are three different kinds of memory systems. These are associated so each entry in one system is associated with various entries in the others. This follows the model used in cognitive sciences. The three systems are:

Episodic memory: The *Episodic Memory* is the part of the memory which consists of the personal history. Things which have happened to a person are stored here. Examples would be memories about childhood or the last holiday. A description for an episodic memory architecture can be found in [DGLV08].

Semantic memory: This part of memory represents or factual knowledge. Things which are not unique to one person but is shared among people, such as meanings, facts, categories and the like, are stored here. Examples would be "a table is a piece of furniture" or "London is the capitol of Great Britain."

Procedural memory: Perpetually executed motor skills are stored here. These skills are consciously learned over some time. With greater experience the conscience is only used when something unexpected happens. Examples would be walking, swimming or riding a bike.

Additionally in this model Freud's *Super-Ego* is viewed as a memory system. The *Super-Ego* tries to restrict actions in order to fulfil demands which were learned in childhood. It contains rules, which have been taught by society and are expected to be obeyed by its members. If a scenario is perceived which fits a stored scenario in the *Super-Ego*, it is sent to the *Ego* together with the information of the expected behaviour. There it has inhibiting influence on undesired actions and reinforces the tendency to do desired ones. For each of these memory systems there are, according to Solms and Turnbull [ST02, p.140-146], three basic functions of the memory:

Encoding: The process of transforming a perception into a representation the brain is able to store.

Storage: Once the perceptions are encoded, they can be stored within the memory system. But not all perceptions are stored. Only the ones which seem to be important enough. Two important concepts are used in the storage process. Consolidation is the process of connecting entries with other entries and thus forming associations between them. This makes memory entries harder to forget, which is the second process. If an entry is assumed to be less important and is not accessed over time it will become harder if not impossible to access.

Retrieval: The process of fetching memories for the memory system. This can happen deliberately by trying to remember something. Or it can happen spontaneously through associations.

The pre-decision unit is the equivalent of the *Id* in Freud's model and consists of the drives and the basic emotions. The basis for internal perceptions are drives. Every system in the body tries to stay within a certain working range (homeostasis). If the values deviate from the set point, the system sends a message to the psyche to take actions against these urges. This is the *drive*. The *drive* triggers an activation to search for something which is able to relieve these urges and bring the system back into homeostasis. For example if someone experience hunger, he tries to get something to eat. Thus the *drive* is a measure of activation which tells the psyche that something has to be done in order to satisfy a certain urge. These *drives* influence the so called *basic emotions*, a term defined by Panksepp.

In [Pan98] Jaak Panksepp described four basic-emotion command systems. The basic emotional system which is mainly connected to the drives is the SEEKING system [Pan98, p.144-163]. A drive can activate the SEEKING system, which causes the individual to search for something to satisfy the need. In general the activation causes an undirected search. The memory system provides a representation of objects which in the past were able to satisfy the need. The memory is used as a pattern for the search. This kind of learning requires a reward mechanism. Panksepp defined the LUST system as a subsystem of the SEEKING system. The LUST system activates pleasant feelings which reinforces the seeking of this object in the future. The motor behaviour for exploration is deactivated and instead activates behaviour patterns for consumption. These behaviour patterns are automatically activated when the wanted object is obtained. This activation is perceived as desirable.

The other basic-emotion command systems are the RAGE system, which according to [ST02, p.123-126] is primarily caused by frustration. Panksepp [Pan98, p.187-205] states that it is mainly activated through restriction of freedom and results in an aggressive behaviour towards an enemy. The FEAR system [Pan98, p.206-224] produces the feeling of fear and triggers a flight reaction, which allows the individual to escape a dangerous situation. The PANIK system [Pan98, p.261-279] is a social emotion which is caused by feelings of loss and the separation from other individuals, e.g. a child from its mother. This can lead to panic and even symptoms of depression. Which of this systems gets activated in a certain situation depends on the trigger of the emotion, where the object is located, previous experiences with this object and the attribution of who is in charge. In contrast to basic emotions complex emotions are the result of experiences throughout the life and thus are learned. They are used in more complex situations. They have a cognitive aspect and are usually compared with episodes of the episodic memory and are influenced by the Super-Ego. Some of them are social emotions like shame, hate or compassion.

These emotions are combined with the before mentioned representation symbols and are merged to a scenario. These scenarios are distributed to the decision unit and the *memorizer,* which stores them together with the external and internal state and the emotions in the *Episodic Memory.*

There are three different ways the model can reach a conclusion on how to behave in a certain scenario as described in [DLP+06]. Each of them has its own module in the model. The most simple one is the *reactive* system which produces a fixed response when the individual is presented with a certain situation. The *routine* unit has two different kinds of routines. The instinctive routines are much like the reactive unit responding to a certain scenario, except that it usually involves longer sequences of action. The intentional routines have to be triggered by the decision

unit. These sets of actions run until either the routine is not appropriate for the situation anymore, the decision unit terminates it, the action sequence has reached its end or another routine takes over.

The decision unit represents the Ego in Freud's model. The Ego is the mediator between the demands of the Id, the claims of the Super-Ego and the requests of reality which are represented by perception, pre-decision and Super-Ego. The Ego is responsible for making plans for actions, thinking without taking action, the steering of attention, speech, motor functions and defence mechanisms. The decision unit is able to inhibit actions which would be carried out based on reactions or routines.

This is the first model which was created for the ARS-project in order to create a unit for perception and evaluation. During design and implementation a major flaw became obvious. This model consists of different theories. Some psychoanalytical theories were used along with other theories from neurology, AI, psychotherapy and behaviourism. Some of these theories are overlapping, others are either contradictory in theory or are conflicting in the solution. Due to these problems the project team started to develop a new model.

2.3.2 The New Top-down Design Approach

As mentioned at the end of the previous section the first model created for the ARS project had some shortcomings. A new model was needed which originated in a single theory. The insights from development of the first model resulted in the decision that the second topic model and closely related works from Sigmund Freud should be the theoretical basis for the second ARS model.

As described in [DFZB08, p.57-64] the ARS model is designed with a top-down approach. The new decision unit consists of three modules on the topmost level. The *Sensor interface* is responsible to gather the information provided by the system's sensors. This information is then passed to the *Psychic apparatus* which makes the decisions based on the provided information. The intended actions based on the decisions of the *Psychic apparatus* are then sent to the *Actuator control*.

The *Psychic apparatus* is divided into three parts which accord to the second topic model of Freud. These sub modules are the *Ego*, *Super-Ego* and *Id*. The *Id* receives information input from the body and sends demands to the *Ego*. The *Super-Ego* is only in contact with the *Ego* and evaluates its actions and decisions. The *Ego* is the centre of the information flow. It receives input from the environment, the *Id* and the *Super-Ego* and executes actions through the *Actuator control*. Between these modules data is exchanged through interfaces, which are only used for information but not for control.

Id

In Freud's model the *Id* is the only part of the mental apparatus present at birth. The *Ego* and *Super-Ego* evolve out of the *Id*. It is dominated by the drives and the resulting desires for immediate satisfaction. These drives are the psychic representation of a bodily need which wants to be satisfied. They can be conflicting and the desires are uncompromising with regard to reality. It has no perception of time, space, consequence or causality. The satisfaction of the drives is its most important goal.

A drive has an organic source which is not in homeostasis anymore. This creates a need which is turned into a psychic process by the use of affects and presentations. This need cathects psychic energy to the drive. The drive gets discharged if a certain goal is reached through a drive object. The object is the means to get rid of the tension created by the drive.

The processes of the *Id* are unorganised and are often even contradictory. These are the primary processes. If they reach the *Ego* and get included into the decision process they get organised and ruled by the secondary process. If an action which should reduce tension can not be executed the charge of the drive is tried to be redirected by the *Ego*. Conflicts in technical systems often lead to failures of the system. However, conflicts in the *Id* can coexist and do not stop the Id from functioning.

The *Id* of the ARS model consists of three sub modules. The *Physiological to Psychic Transformation* samples the physiological needs and converts them into mental information processable for the mind. These representatives are affects and presentations. They can be seen as a drive and are the connection between physiological and psychic processes.

The result of the conversion is the input for the module *Quantification of Drives*. Here the representatives are cathected with psychic energy and evaluated. This determines the priority of the drives. These messages are then sent to the *Ego*, where they are arranged and structured.

The third part of the *Id* is the *Selection of Memory Traces*. This part is concerned with the generation of memory traces and their activation, called cathexis. An object can be represented in two ways in the memory. Thing-presentation refers to the sensoric impression an object leaves in the mind. They are mainly stored in the *Id*. Word-presentation is a symbolic representation of an object or event. Usually some kind of symbolisation is used, for humans most likely a verbal expression. These word-presentations are mainly used in the Ego for thinking. Memory traces in the *Id* consist of thing-presentations. They are characteristics from the perceived information and form a pattern, which is reactivated when the object is perceived again. The according memory trace gets cathected with energy again by the module *Selection of Memory Traces*. The amount of energy cathected to the memory trace depends on the stimuli from the body or the environment. If no matching memory trace is found a new one is generated. In general more than one memory trace will, at least partly, fit the input. In this case the one with the highest percentage of accordance is activated. If some memory traces are activated together, they become associated. This connection is called facilitation.

Super-Ego

The *Super-Ego* develops in childhood from the *Id* and the *Ego*. It internalises and represents restrictions and demands from parents, teachers and society. The child learns to repress certain drive demands which are in conflict with the demands and restrictions of society. Demands and restrictions are managed in the *Super-Ego* and it gives feedback on actions of the individual. The feedback can be positive or negative and can be seen as some kind of reward system. The *Super-Ego* causes the *Ego* to revaluate certain desires and maybe suppress them if they do not fit into the stored restrictions and demands. The *Super-Ego* receives the perceptions from the *Ego*, evaluates the situation and returns a behaviour recommendation. This recommendation can be in conflict with demands from the Id or reality, which the *Ego* has to resolve.

The *Super-Ego* consists of three modules. The *Management of demands* handles the expectations of others based on social norms. It influences ideal behaviour and thinking. The *Management*

of restrictions issues restrictions on behaviour and thinking. It is formed in early childhood but becomes supplemented in later years. These two modules are formed by the social background. The *Management of the ego ideal* is developed during childhood in interaction with role models, like the identification with role models, and represents what the individual personally wants to be like.

Ego

The *Ego* is a mediator between the demands of the inner and the outer world, the *Super-Ego* and the *Id*. Initially after birth the psychic apparatus is controlled only by the pleasure principle from the *Id*. The discharge of the drive demands happens independently from the environmental condition. Over time the *Ego* develops from the *Id* as a result of the demands of reality. It is the only part of the psychic apparatus which is in contact with the environment. The information of the outer world is passed on to the *Super-Ego* and the *Id*. This information evokes a preferred action in the *Id* and *Super-Ego*. If a conflict arises between the decisions of the *Id* and the *Super-Ego*, the *Ego* has to balance them. This is done by the *Decision management* module.

In the ARS model the *Ego* is divided into two functional modules. These modules are *Psychic synthesis* and *Executive motor functions* consisting of various sub modules.

The first is the *Psychic synthesis*, which is the mediator between, *Super-Ego*, *Id* and outer world. It receives information from the *Id* about current drive demands, and from the *Super-Ego* about relevant behaviour rules for the current situation. All modules of the *Psychic synthesis* deal with the resolution of the conflicts between *Id*, *Super-Ego* and outer world. It consists of nine modules.

Perception receives internal and external information. If the situation is not completely new, memory traces are activated, which otherwise would have to be created. A special modality of perception is the attentive perception. It accords to observant thinking and is related to the *Focus of attention*. The *Focus of attention* module evaluates the information provided by the *Perception*. It controls the search for a required object according to an activated presentation demanded by a drive. It selects the incoming information in search of a specific information acting as a filter. The information which it searches for, depends on the amount of energy cathected to the information. It tries to optimize the perception process and accelerate the reaction to environmental changes. The selected information activates existing memory traces in the *Presentation management* module. This module organises the activation of thing-presentations and other associated thing- and word-presentations. It also manages the facilitation between them, which are mainly, but not exclusively, formed in early childhood. The presentations are one part of a drive component which gets activated when a stimulus is received from the environment. The other part are affects which are managed in the *Affect management* module. According to Freud [Fre15, p.117-140] affect is a quantifiable psychic representative of a drive. These affects can be for example joy, interest, fear or anger. The *Thinking* module converts the primary-processes of the *Id* into secondary-processes which are influenced by culture. The thinking process uses memory traces, facilitations, affects and thing- and word presentations to compare a situation with previous experiences. New memory traces can be formed by the thinking process. It can plan actions without actually acting them out in order to foresee results and pick the one which is expected to be the best. This can be used to avoid dangerous situations and save bodily energy. The *Reality testing* ensures the separation of reality and imagination formed by inner presentations. If the module fails the individual can get harmed if it misinterprets a situation. After birth the individual is not able to distinguish between the inner and outer world until it

learns the difference during childhood. If a drive cathects an internal presentation, the attention is focused on the drive object. If a possible match is found in the environment, it is compared to the activated presentation. The *Memory management* handles the memory traces placed in the *Ego*, which include word-presentation as well as thing-presentation. The information can also be handed to to the *Selection of memory traces* module of the *Id*. The *Decision management* handles occurring conflicts which result from the information provided by *Reality testing*, *Perception* and the *Super-Ego*. This information is integrated with the demands of the *Id*. The module now decides what the best action for this situation would be. A decision is made and the information is sent to the involved modules and it tries to mediate between the demands. If some demands can not be satisfied by the decision, the *Ego's* mechanisms of defence will attend to them. The *Mechanisms of defence* deals with conflicts between drive demands and the *Super-Ego* on the one hand and the environmental situation on the other hand. Those conflicts which can not be resolved at the moment are repressed by a censor in order to hinder their entrance into the conscious mind. The *Ego* decides which thoughts the mind is aware of and which stimuli are allowed and which are forbidden. Different mechanisms of defence are possible, depending of the current inner and outer world. The mechanisms are influenced by the *Decision management*, which decides which drive demands are to be repressed or distorted and which instinctual aims are to be displaced, suppressed or inhibited.

The second part of the *Ego* is the *Executive Motor Functions* module, which is concerned with perception and motor control. It has two sub modules, namely the *Focus of attention management* and the *Motility control*.

The first is the *Focus of Attention Management*, which controls the *Focus of attention* module of the *Psychic synthesis* module in the *Ego*. The *Focus of attention management* takes care of the motor functions required for the focus of attention. This process should advance the reaction on condition changes and optimise task execution. It is activated by *Psychic synthesis* processes, which require specific informations. The second sub module is the *Motility Control*, which is controlled by the *Decision management* in the *Ego*. It manages the control of the body's motility and motor driven actions.

2.4 Artificial Life

As already indicated, the model previously described is going to be applied for various applications. But before any of these models will be used in critical applications, it is necessary to determine the capabilities of the constructed models and if their abilities satisfy the expectations. Therefore a testing environment for the model is created. Within this testing environment the models are integrated into artificial living beings. These beings situated in an environment is called Artificial Life (AL or Alife). AL is sometimes associated with the field of Artificial Intelligence (AI). Another topic that is related to these two is agent systems. These principles have some things in common but none of them is an complete sub field of the others. First an introduction to these three disciplines is given. What they have in common and where their differences are is also explained. In the following section the general purpose of AL-systems is outlined and some examples of AL-systems are given. The ICT is developing its own Artificial Life system which is called the Bubble Family Game (BFG). This simulation environment and its previous implementation is introduced in the last section.

2.4.1 Definition

In order to explain what Artificial Life is, it is probably best to start at its origins in the field of Artificial Intelligence. There are two main branches of AI. One branch tries to understand how individuals, especially humans, think. It tries to use these findings to create artificial units that are able to produce some sort of output which can be seen as "intelligent". The other branch of AI is mainly concerned with logic and how to draw valid conclusions from given data. This field of AI is usually concerned with topics as planing, knowledge representation, searching, decision making, learning and others. Russell and Norvig [RN95, p.1-5] subdivide the field of AI into four classes:

Systems that think like humans This approach tries to simulate the way humans solve problems. The focus is not so much on the correct result of a computation but more on the way the system reaches this result. Cognitive science tries to combine AI and psychology in order to create feasible models of the human psyche.

Systems that act like humans Here, the intent is to make computers act like humans. The question is if a computer is sophisticated enough to trick a human being into believing, that he is interacting with another human being, it is assumed to act like a human. In this case humans are assumed to be a qualified judges. This test was designed by Alan Turing in 1950 and is unsolved so far. Critique about the Turing Test was expressed by Galatzer-Levy [DFZB08, p.369-382]. He notes that the test omits many central attributes of the human mind. In his opinion the test focuses on the rational capacities, but does not take the irrational part of the human mind, like playing for example, into account.

Systems that think rationally These systems rely basically on logic, in order to solve problems. The correct result of the computation is of importance. The underlying mechanisms are only modified if the result is not satisfactory. The mechanisms depend on an exact notation for knowledge representation and manipulation rules. This is one of the main problems of rational systems. Knowledge, especially informal knowledge, is not always easy to represent. Facts can be uncertain or change over time. Another problem is the complexity of some problems, which makes practical computation hard if not impossible.

Systems that act rationally In order to act rationally the system needs some sort of body with which it can experience its environment and affect it. Part of being able to act rationally is to be able to think rationally. The explanation mentioned in the point above is also applicable here. The problem is, that acting rationally in the world is not easy. Often inferences are required, without having all necessary information.

The systems described in the last point have ultimately lead to the the concept of agents (*agent* from latin *agere*, do, act, make). Depending on the definition, an agent has various attributes, which make him an agent. Russell and Norvig [RN95, p.32] define an agent as:

Agent An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators.

This definition would make anything that senses or measures something and acts on that an agent. Anything containing a control cycle, like for example a thermostat, which hardly would be called *intelligent*, would be regarded as an agent. Wooldridge's [Woo02b, p.15] gives another definition of an agent:

Agent An agent is a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives.

This definition equips an agent with some characteristics, which are widely accepted as being fundamental to an agent. These characteristics, together with the social ability to interact with other agents, state that an agent has to be *flexible* to reach its goals. The three characteristics are:

Autonomous: The agent is able to act on its own without being constantly told what he has to do. This is the main difference between an agent and a standard software program.

Proactive: The agent does not purely react to events in its environment. He has a specific goal and initiates actions on its own in order to accomplish it.

Reactive: Since the agent is situated in an environment, he usually has to react to changes which occur in this environment and might obstruct his efforts to reach his goals.

First these points and the definition will be considered in a little more detail. An agent is situated in an environment. This situatedness means that he does not have to deal with abstract but concrete information. The agent is part of this environment and everything he does influences the environment. In reverse some changes in the environment, regardless of who is responsible for the changes, affect the agent. The purpose of the agent is to reach a certain goal. This goal might be intrinsic insofar, as the agent has certain needs and tries to fulfil them through something the environment provides. If the goal is extrinsic it is usually provided by a user, who tells the agent what he want him to achieve. Regardless if the agent is intrinsically or extrinsically motivated, he takes actions in order to achieve his goal. This usually involves some sort of planing, searching and reasoning on provided data.

If the goal of the agent is to fulfil the demands of a user, it means that the user only defines the goal. How the agent reaches the goal is not explicitly specified. A normal program function is able to execute a task when an input is given and return an output. But within this function the programmer has to explicitly specify how this task is accomplished. An agent does not get this explicit flow of actions, but has to autonomously determine a feasible solution on his own.

In order to reach this goal in his environment, the agent has to react to his perceptions of the environment. There are various characteristics an environment can have. Russel and Norvig [RN95, p.40-44] give a classification of possible properties of the environment:

Fully observable vs. partially observable: If the agent can observe the whole environment at any point in time it is called fully observable. In this case the agent can sense any aspect, which might be relevant for his decisions. In this case the agent does not have to store an internal representation of the world. The environment can be partially observable because the sensors of the agent are not fully operational. Some features of the world could not be observable with the sensors of the agent. Or the world is simply to large to be fully observed by the agent's sensors.

Deterministic vs. stochastic: A world is deterministic if the any changes in the environment of the agent is purely dependent on its actual state and the actions of the agents. If the future state of the world depends on other factors, it is called stochastic. A partially

observable world might occur stochastic to the agent. Also a deterministic world which is complex enough might appear stochastic to the agent. A deterministic world in which the only stochastic aspect are other agents is called *strategic*.

Episodic vs. sequential: In an episodic environment the evolution of the world from the agents point of view is parted in episodes. These episodes are independent from each other and only the current setting is relevant for the action of the agent. Past and future states of the world are of no concern. In a sequential environment the past states of the world can have relevance on the current state. Any action of the agent must be considered as influential for the evolution of the environment.

Static vs. dynamic: If the changes in the world depend solely on the actions of the agent it is called static. In this case the agent does not have to observe the environment or take time into account while making a decision. If the world can evolve while the agent sits around and does nothing it is called dynamic.

Discrete vs. continuous: The differentiation between discrete and continuous depends on what it is applied to. If the state of the world is discrete there are a finite number of distinguishable states. A continuous world changes from state to state without clear transitions. If time is discrete it is divided into slices and every event in the world can be assigned to a specific time slice. Also the actions and perceptions of the agent can be discrete.

Single agent vs. multiagent: This basically determines if an environment contains only one agent or if the agent has to take other agents into account. This matter is discussed below in more detail.

According to these definitions the worlds can have different levels of complexity. The most complex environments are partially observable, stochastic, sequential, dynamic, continuous environments. As mentioned before, the agent has to be able to autonomously pursue various goals in the world and react to its possible changes. Therefore an agent has to be flexible to meet his objectives.

That still leaves the question if agent design is not just a part of AI. After all the goal of the research in the AI field is to solve real world problems. This should be achieved through planing, searching and the like, and reactions to changes, for example in non-monotonous logic. Under these aspects it is true, that various fields of research in AI influence agent technology. But as Wooldridge [Woo02b, p.9-10] states, AI is merely concerned with improving the components such as planing. Agents use these findings, but take one step further. They try to integrate these components into one entity in order to create a decision unit. This would suffice to make AI a sub field of agent design. Russell and Norvig have wrote their introductory book to AI under the premise that it is all an attempt to create an intelligent agent. But there is one more point to make when concerned with agents which is completely omitted by AI research. As mentioned above when describing the distinctions in agent system environments, an agent does not necessarily exist alone in his world. However, most expert systems are not interacting with other expert systems. Agents on the other hand often exist in environments where other agents are present. These other agents also try to reach a goal. They can be competing in their actions or they can cooperate. In either case they have to interact with each other. Therefore as soon as another agent is present in the environment, the agents have to posses one more characteristic in addition to autonomy, proactiveness and reactivity. Agents have to be social.

Social: Being social means the agent has to have the ability to interact with other agents in order to reach its design objective.

This usually is no trivial task since the agents have to have a common language through which they can communicate. Also the task of coordinating the actions of the agents to cooperate for their goal is not easy. Various approaches have been developed for agents. These include belief-desire-intention architectures, logical agents, reactive agents and layered agent architectures. A short overview for these approaches is given in [Woo02a].

The possible applications for the so called Multi Agent Systems (MAS) or sometimes Agent Based Modelling (ABM) are various. More playful applications are Robocup [4] or computer games. More practical ones are webcrawlers for information gathering in the World Wide Web (WWW), a paradigm for software engineering or tools for simulating societies. This last application is the important one for this thesis. The creation of a society of "living" beings within a computer. The field which is concerned with this topic is called *Artificial Life* (AL or Alife).

Mankind has entertained the idea to create artificial life for over two thousand years. In ancient greek mythology a statue made by Pygmalion comes to life. In medieval times the concept of Homunculus was created, which was picked up even by Paracelsus. He even gave a description how to create life without birth. The most well known example of creation of artificial life today is still Mary Shelley's Frankenstein. In this book a scientist creates an artificial human being. In the terminology of artificial life, these kinds of Alife based on biology would be considered as *wet* Alife. In contrast Alife based on hardware, like robots, would be called *hard*. Alife existing just within the computer as software agents would be classified as *soft*. Since biochemistry and robotics is not within the scope of this thesis, it will concentrate on the field of *soft* Alife.

Before any attempt of creating life artificially, it might become necessary to define what can be considered as life. Of course there are various definitions of life depending on the source. The most common structural and dynamic attributes are according to [Bro06]:

Metabolism: The ability to obtain matter from the environment, its travel through the individual, its chemical transformation and the disposal of the remnants to the environment. The purpose of this action is usually to obtain energy. Breathing is sometimes mentioned as a separate attribute of life, but can be seen as part of having a metabolism or other life forms do not depend on oxygen at all.

Reproduction: Reproduction can be either sexual or asexual. Asexual reproduction is bound to mitosis and produces offspring that is genetically identical with its ancestor (save mutations). Sexual reproduction is bound to meiosis and the joining of two haploid gametes from two genetically compatible individuals.

Modification of the genome: In every living being there is some information stored which contains the construction plan and basic behaviour patterns for the organism. This information can be changed through mutations, which are random changes within this information. In sexual reproduction the information from both parents can be recombined. This creates a mix of the parents genetic information, which is inherited by the offspring. This modification is the basis for evolution.

Some sources, for example [Mey83] state other additional attributes like growth, being composed from one or more cells, possession of certain cellular structures or excitability. Most of these are

corollaries from the above mentioned points. Also most of the mentioned attributes are not found in some populations but for our needs they suffice.

As Bedau [Bed03] explains the development of artificial life has its roots in Turing's automata theory. This in turn influenced von Neumann's theories of self-reproducing automata and Wiener's information theory and analysis of self-regulatory processes. These theories led to the development of cellular automata. A cellular automaton is a grid of cells where each cell can can be in one of several finite states. These cells can be viewed as finite state automatons. These states are updated in discrete time steps, where each new state depends on the current state and the state of the cells in the neighbourhood. Some deterministic rules define how the state of the automaton changes. The best known example of a cellular automaton is Conway's Game of Life, which is described in Section 2.4.3. These cellular automaton did show, that very complex structures can emerge from a few simple rules. If viewed on a macro level, these structures can be seen as being able to react to their environment and reproduce.

Artificial life also borrowed many concepts from the field of AI. Genetic algorithms were heavily influenced by the mechanisms involved in reproduction and modification of the genome as described above. Learning is viewed as a competition among solutions which are encoded as artificial genes. Each solution is evaluated through a fitness function. Solutions with better "fitness" are more likely to be combined with other solutions through crossing over, which is mixing the solutions. The result can then be mutated to induce new solutions.

As previously mentioned an agent can be assumed to be able to autonomously pursue a goal and react to its environment and other agents. This assumption can be combined with the idea of a life form, which has a metabolism and can reproduce. Additionally it can have some sort of information about himself and his behaviour stored within himself and is able to modify his behaviour. If these assumptions are combined, it leads to a more intuitive form of artificial life. This introduces a system where artificial agents are given properties that are considered as properties of living beings. They live, feed, breed and interact within an artificial environment.

This shows that AI, Alife and agents have much in common, but are not to be confused with each other. AI concentrates on intelligent solutions to problems which can be carried out by computers. These may be based on logic or by modelling the human common sense. What AI lacks in comparison to agents is the social component which allows agents to interact with other agents. Also the situatedness in an environment, which can be sensed, acted upon and gives feedback for the agent's actions, is missing. AI is also not concerned with many of the aspects which make a system "alive". Agents use techniques developed by AI researchers which are applied to intelligent agents for carrying out tasks on behalf of human demands. But these techniques are often not required when trying to model a social system of living beings by using software agents. Alife is partly interested in AI when it comes to modelling human abilities especially in cognitive functions. The field of agent system is interesting for the Alife community when developing soft or hard Alive systems. But for example the field of automata theory is neither the concern of AI nor of agents.

As Bedau [Bed03] states AI and Alife have a similar methodology for problem solving. They draw their inspiration from natural phenomena and try to model them in order to reach solutions. But their approach is very different. AI models have a serial top-down structure. A central decision unit controls the whole process of computation, which is broken down into small feasible steps. In Alife the methods of natural living systems are modelled. There is no central decision unit present. All individuals display rather simple behaviour. Their perceptions and their actions are only influenced by and affect only their immediate surroundings. But they can execute their tasks

simultaneously and are able to interact with each other. This is a bottom-up approach where the behaviour, which should fulfil a task is rather an emerging result of the effort of the whole collection of individuals.

In Section 2.4.4 the agent system which has been developed by the ICT is discussed. It tries to simulate a simple form of individuals which live in an environment and are dependent in their survival on this environment and the other agents in it. The decision unit which is used to steer them is described in Section 2.3.2.

2.4.2 Purpose of Artificial Life Systems

Alife systems model some properties which are usually associated with real life. As [Bed03] mentions the most obvious application of Alife in computer science is in the field of genetic algorithms, where the mechanisms found in procreation through genes is modelled. This is used in order to have heuristics for problems which can not be solved with algorithms or at least no algorithm is known. These heuristics are not optimal, meaning they do not guarantee the best result there is for a problem. But an acceptable result can be expected from these heuristics. Mechanisms of the immune-system are used for anti virus programs on computers. The model of living cells and the interaction between them is used for models of computation [Pau06].

Luger [Lug01, p.536-539] describes the application of Alife systems in biology to study what is possible in the evolution of life. Many occurrences in nature and in the development of the species happens by chance. And even if the amount of living beings, which have evolved over time, is vast, it can not be sure if all regularities which are involved can be discovered when only regarding what really took place. Only by understanding what could have been, what possibilities have been eliminated by fate, maybe it can be understood what really happened. By making simulations of life forms which play with alternative outcomes, a deeper understanding about the mechanisms of evolution are desired. If a new simulation of life is started and some properties are changed, what changes and what remains the same can be studied. Finally, what is inevitable in the evolution of life may be predicted.

In the same way as evolution can be simulated also societies and their behaviour is of interest. The interaction of individuals and the emerging behaviour of populations from the behaviour of individuals can be studied. This is closely related to the question of the emergence of intelligence in living systems. And what counts for whole populations can also count for single living beings. The emergence of possible intelligence of a single individual from the parts which form its brain is of interest. As well as how the biological evolution and the evolution of intelligence is related to the evolution of social structures and culture?

Some of this questions are the target of the research of the ARS project and its testing environment, the Bubble Family Game in Section 2.4.4. The behaviour of an artificial mind is going to be examined in an artificial world and a social setting. In this world the functioning of the mind can be tested. This will also result in a deeper insight into the theoretical background for the model. The emergence of behaviour which was not implemented in the model is the main target what this thesis is about. It will be studied what emerging behaviour patterns can emerge from the functions implemented in the brain and how they can be tested. Therefore agent based Alife systems provide the theoretical background for a testing environment for the Bubble Family Game.

2.4.3 Examples of Artificial Life Systems

In this section two examples of Alife Systems are given. The first one is Conway's Game of Life. It is probably the best known cellular automaton. The second example is Masanao Toda's Fungus Eater. It is an example for an agent based Alife system.

Conway's Game of Life

The Game of Life was first described in [Gar70]. It consists of a grid where every field can be either alive or dead. If a cell is alive or dead in the next time step is determined by the eight cells around it. At every time step three rules are applied to every cell and all births and deaths occur at the same time. The *birth* rule states that if three adjacent cells are alive and the cell in the middle is dead the middle cell also becomes alive. A cell will *survive* if two or three adjacent cells are alive and the cell in the middle is also alive. The *death* of a cell occurs if one or no adjacent cells are alive. Then the cell in the middle dies of loneliness. If more than three adjacent cells are alive the middle cell dies of overcrowding.

Even if the rules and the setting are very simple it already shows the dependence of life on itself and its environment. But even more interesting are the emerging patterns from the interactions of the small individuals. Figures can be stable, oscillate by returning to a previous state after some time, they can move around or eventually simply vanish completely.

The rules for a living cell are relatively simple. But the emerging patterns can hardly be foreseen. As in real life, small changes of only one cell can have drastic consequences.

Toda's Fungus Eater

In the 1960s Masanao Toda developed the world of the Fungus Eater as a thought experiment [Tod82]. The Fungus Eater is a robot which is sent to another planet called Taros. His task on this planet is to collect uranium ore, which is scattered over the planet. The Fungus Eater should collect as much uranium ore as possible. His reward will be proportional to the amount of uranium ore collected. On the planet there are also fungi growing. In order to keep his biomechanical engine running he has to collect and eat these fungi for his nutrition, hence the name Fungus Eater. But in contrast to the uranium ore the fungi's only purpose is to keep him alive. His reward is entirely independent of the amount of fungi collected and consumed. Every activity of the Fungus Eater, including moving around, collecting ore or fungi as well ass brain functions, like deciding what to do, consumes a certain amount of his fungi reserve. If the fungus eater runs out of fungi, he can not take any actions anymore.

This relatively simple setting alone poses a conflict for the Fungus Eater. His overall goal is to maximize the amount of uranium ore he collects. But therefore he needs the fungi to keep alive. He has to decide if he should collect uranium ore to gain more reward or if he should collect fungi to increase his chances of staying alive. If fungi and uranium ore are not existing in the same place he needs to decide what do to first and when to switch to the other.

To make the setting more complex, various other factors can be introduced. For example obstacles or changes between day and night can make his decisions harder. These additional factors force him to put additional effort into his problem solving strategies. He has to make decisions which require him to plan further ahead. But planing and thinking will cost him energy, which he also

has to take into account. This setting gets even more complex, when other fungus eaters are introduced into the world. This requires a single fungus eater to be able to cope with a multi agent system. This includes not only that other fungus eaters are taking actions which he can not foresee and can make his previous plans obsolete. It also means that he might even have to cooperate with the others.

Toda stated that equipping these fungus eaters with emotions would be crucial for their success. Their intellectual abilities would not be as important. Toda calls these emotions urges which he combined into groups. Only some of these urges are comparable to what is intuitively understood as emotions. Others have more similarity with Freud's drives or social abilities. For example Pfeifer [Pfe94] used the Fungus Eater for his research on the importance of emotions.

Toda was one of the first to create a theoretical world in order to research the behaviour of artificial beings. These beings can already be called agents. They have to act autonomous in their decisions and actions. They have goals to pursue which makes them proactive. And they have to react to changes in their environment. This requires flexible agents which in case there are other agents present would require them to be social. This leads us to the notion that Toda's Fungus Eater can be considered as an example of an agent based soft Alife mentioned in Section 2.4.3.

2.4.4 BFG

The Bubble Family Game (BFG) has been created at the ICT. The aim of the ARS project is to develop a decision unit for automated systems, which is able to deal with unforeseen and diverse problems. The underlying principle for this decision unit is Freud's second topic model of the human mind. The implementation required a "sandbox", where the correct functioning of the modules could be tested.

The inspiration was provided by Masanao Toda's Fungus Eater, explained above. In the style of the fungus eater a simulation environment has been created. The Bubble Family Game simulates a world with objects and provides bodies for the agents called Bubbles. Through these bodies the agents are situated in the world and are able to experience it through sensors and act on it through their actuators. Their mind is provided by the implementation of the model presented in Section 2.3.2 and inserted into every Bubble. This decision unit should make the Bubbles able to cope with changing environmental and internal requirements. The overall goal of the Bubbles is to stay alive as long as possible.

The environment of the BFG consists of active and passive entities. Passive entities are the energy sources and the obstacles. The energy sources provide the energy needed by the Bubbles for their survival. The amount of energy in the world that can be consumed by the Bubbles is limited. There are two types of energy sources. The first one can be consumed by one Bubble alone. The other one requires the cooperation of two Bubbles to be consumed. This should complicate the obtaining of energy and enforce the cooperation and social interaction among the Bubbles. Obstacles hinder the access to the energy sources for the Bubbles by blocking the way. If the Bubble collides with an obstacle, his energy level will decrease. Landscapes can slow down the movement of the Bubble.

The active entities are the Bubbles. The Bubbles are put into groups of varying size. These groups are competing against each other. The group of which at least one member outlives all the members of the other team wins. This allows to determine a clear winner and looser group.

Every action of an agent consumes energy, which is replenished through the energy sources. If a Bubble runs out of energy the Bubble dies. Every activity, even mental, requires energy. The Bubbles are for example able to promenade, flee, attack and eat. The Bubbles are able to experience emotions, have memory and are able to make decisions based on strategies. They are also able to interact on a basic level to each other. To test their abilities some test cases were developed:

Ask for a dance If a Bubble has the desire to dance with another Bubble, it calls out to one in hearing range. The other Bubble decides if he wants to dance, depending on the social level and emotional state. If he rejects, the asking Bubble calls out a reproach. This lowers the social level of the other Bubble, which in turn lowers his chances of getting help later. If he accepts, he moves towards the other Bubble and they start to dance. This increases his social level. The social level is known to all other Bubbles.

Cooperation for food As mentioned before some energy sources can only be accessed through the joint effort of two Bubbles. Again a Bubble can call for help from another Bubble. As in the dancing scenario a rejection leads to a decrease of the other Bubbles social level, whereas an acceptance leads to an increase.

Call for help If one of the Bubbles is attacked by an opponent the Bubble has two options. He can either flee or call for help if he senses another Bubble from his team in hearing range and decides to defend himself. As before the called Bubble has the options to decline which leads to a reproach and the decrease of the social level of the called Bubble. Or if the other Bubble decides to help, he will be praised and his social level will increase.

Unlike in Toda's fungus eater the Bubbles can only collect energy for their nutrition. The uranium ore has no equivalent. Instead the competitive goal of outliving any member of the other team was introduced. Together with the above mentioned abilities to interact this introduces a new kind of conflict. The Bubble has now to calculate his options. He can either look for its energy resources or he can help his team mates to survive. The tests mentioned above test mainly the social interaction among the Bubbles. Other test cases where developed which again where mainly unit tests. What was lacking until now was the ability to test not only behaviour which has been implemented. Since a model of the mind has been implemented with several modules of functionality it is of interest what possible behaviour can emerge which has not been implemented but arises out of the combination of the individual functions. The goal of this diploma thesis is to define some cases of emergent behaviour which are of interest and to determine ways how these emergent behaviour patterns can be tested.

The first implementation of the BFG was done in AnyLogic. AnyLogic is a dynamic simulation tool based on Java which allows the development of simulations with an agent based approach. A picture of the 3D display of the BFG can be seen in Figure 2.3. The spheres represent the Bubbles and the energy sources are depicted as rings.

The critique of the ARS project team was that AnyLogic is a suitable tool for rapid prototyping. But it is inadequate for a full implementation of the BFG. Therefore a new framework was needed for the new implementation. This issue will be further explored in the next section.

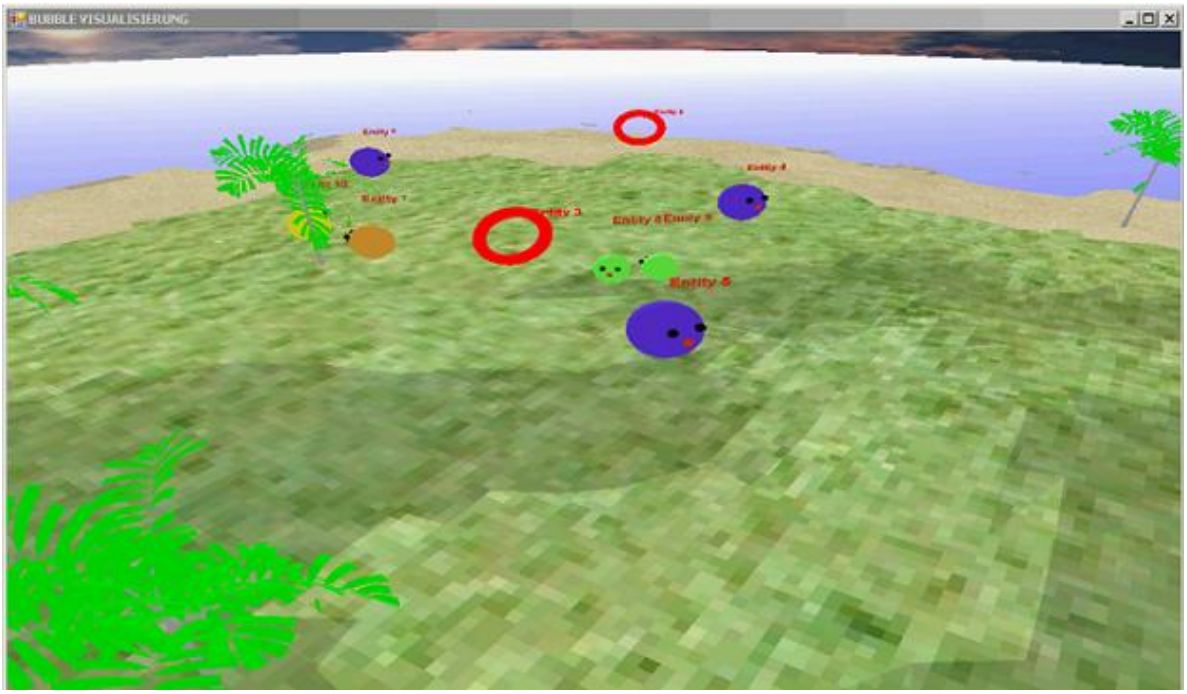

Figure 2.3: The 3D view of the first implementation of the BFG in AnyLogic.

2.5 Agent Based Systems

As mentioned before in Section 2.4 multi agent systems can be used for various purposes. These include fields like biology, sociology or chemistry. Scientists in this fields who have extensive knowledge about programming a simulation environment are rather the exception than the rule. Further the basics for these simulation environments are often very similar. They only differentiate in the details. The underlying properties and requirements, like being able to create a grid world and having a scheduler, which controls the passage of time, are the same in most simulations. Therefore various frameworks have been developed in order to facilitate the development of simulations. These frameworks provide the functions which are needed in most simulations independent of their purpose. Of course some of these frameworks also provide modules for rather specific tasks, like libraries for genetic algorithms.

In an internal paper written prior to this thesis, the author compared two widely used frameworks which were candidates for a new implementation of the BFG. These frameworks were *Swarm* and *Repast*. A short summary of the paper is given in the following.

Swarm

Swarm was developed in order to have a reusable framework that can be adopted to many different kinds of simulations. The basic idea of Swarm is a collection of agents, called a swarm. Each agent can itself be a swarm by holding a collection of agents thus building a hierarchy of agents. A schedule defines, at discrete points in time, when each agent can act. Various probes can be used to observe the model. Swarm was originally implemented in Objective C. Today there is also an interface for Java available. The software and documentation can be found on the main site for swarm [5].

Repast

Repast (REcursive Porous Agent Simulation Toolkit) was originally developed by the University of Chicago and the Argonne National Laboratory. Today it is managed by the non-profit, volunteer organization ROAD (Repast Organization for Architecture and Development). Repast borrowed many concepts from Swarm. In Repast the developer is not forced to use a hierarchical structure for the agents as in Swarm. The scheduling concept was adopted. Repast offers more tools to represent the world and create probes and graphs. Repast is an open software project and in contrast to Swarm a native implementation for Java (among other languages) exists. The software and documentation can be found on the main site for Repast [6].

Swarm and Repast are similar in some areas since Repast was inspired by Swarm. But Repast is more than just an add-on for Swarm. Repast is as a complete new toolkit for agent systems. Some concepts Swarm introduced were quite useful. These were transferred to the Repast system. Swarm was initially programmed in Objective C which may lead to some performance advantages. But on the other hand this makes the system hard for Java programmers to use since the source code is hard to read for someone not familiar with C. Therefore it is easier for Java programmers to adapt the Repast system to their needs or to find out how certain functions work or to trace errors. Although the basic features are the same for both systems, in Repast they are much easier to handle. The documentation for both systems is extensive. The main difference is, that with Swarm not all of the documentation is written for Java programmers. Many principles have to be translated from Objective C to Java and looked up in the examples, which are few for Swarm in contrast to Repast. Although both systems are quite similar, Repast is in all categories at least as good as Swarm.

MASON

Ultimately another framework has been chosen for the implementation of the sandbox for the new top-down approach. The selected frameworks is called MASON which stands for "Multi-Agent Simulator Of Neighbourhoods... or Networks... or something..." as described by the MASON website [7]. MASON was developed by the ECLab (Evolutionary Computation Laboratory) and the Centre for Social Complexity of the George Mason University. The design of the framework was influenced by TeamBots and the before mentioned Repast. It claims to provide a fast, portable and fairly small framework for discrete-event multi agent simulations. The core library is implemented in Java. It offers visualizations in 2D and 3D but the simulation can be run completely independent from any visualisation. Serialization enables models to be checkpointed, recovered and migrated to other platforms. A small and simple physics package for rigid bodies is available. This physics engine will be extended for the implementational part of this thesis. The aim is to add a friction to objects moving along each other. The implementation will be described in Chapter 5.

3 Requirement analysis

This chapter sets the groundwork for the rest of the thesis. The focus lies on the artificial life system Bubble Family Game (BFG). The goal of this work is to define tests for the behaviour patterns of the Bubbles. The intention is to deviate from the usual test routines, which are enforced by theories in software engineering. Instead test methods should be developed, which go beyond the usual test cases in computer science, like module tests or data tests. Its more like an integration test of some sort. The goal is to examine an artificial life (Alife) system, where the individuals have an artificial mind of their own. This mind is the result of the interaction of various modules that each have their own rather complex functions. These interactions have to be coordinated to result in observable behaviour. Through the interaction and coordination of the functions, this behaviour is bound to be emergent from the modules as long as it is not dominated by one module.

The purpose of this chapter is to determine behaviour which can be emergent from the modules. Since the target of the model is the human mind, the idea is to find human behaviour patterns which emerge from the actions of the Bubbles.

In the first Section 3.1 the behaviour patterns, which will eventually emerge at some point, are described by means of their real world occurrences. In the second part, in Section 3.2, the use cases for the behaviour are explained.

3.1 Emergent Behaviour

Sometimes a system where entities interact on a lower level develops complex patterns or behaviour on a higher level. On a lower level the parts of the system are rather simple. Sometimes systems develop complex behaviour on the higher macro level, which was not intended or designed on the lower micro level. If this behaviour evolves through the interaction of the simple parts, these patterns are called emergent. The proverb "More than the sum of its parts" refers to the phenomenon of emergence.

In this section some possible emergent behaviour patterns and their requirements are described. The resulting problem is obvious. Since the behaviour, which is to be examined, is not implemented into the decision unit, it is hard to predict what kinds of emergent behaviour might occur. Furthermore, the behaviour of interest emerges from a technical model of a subjective model of the human brain, namely the second topic model of Freud. Moreover, psychoanalysis was basically designed as an explanation of the workings of the human brain based on its development. It

also provides a form of therapy if something in the course of the development of the personality went wrong. Descriptions of non-pathological behaviour are rather rare in Freud's literature. The emphasis in this work, however, lies strongly on the emergence of "normal" behaviour. Furthermore, this work can only focus on a selection of emergent behaviour patterns, since describing every possible emerging behaviour would go clearly beyond the bounds of possibility. Therefore the selection of behaviour patterns described in this section is necessarily subjective.

The descriptions of behaviour in this section is based mainly on findings in general psychology and social psychology. These are behaviour patterns that are well probed and researched. Some behaviour is explained by more than one theory. This is natural for a science, which is just able to base its findings on observations without being able to observe the mechanisms behind it. If this was the case for a behaviour pattern, the most general theory was taken in the spirit of Occam's razor. If the description of a behaviour is more general, it is more likely to cover some observed behaviour.

Love

The first possible emergent behaviour which should be discussed is love. Basis for the considerations is Freud's last drive model where he assumes two drives, namely a sexual drive and a death drive. Love is a partial drive of Freud's sexual drive. Since the drive model is the basis for the whole model of Freud, it is of interest if important behaviours for real life, such as love or aggression, as described in the next paragraph, occur.

The first question is, what kind of perceptions or behaviour patterns are the basis for being attracted to and loving somebody else? Various factors can influence the feeling of attraction towards another person as stated in [AWA04, p.360-372]. Each of them can increases the possibility for a close friendship or love. The first is the *effect of closeness*. It states, that we tend to like things we see and interact with a lot. We also like people who have a close *similarity* to us. It includes similarity in appearance, beliefs, values and so on. This is important because it increases the chance that the other person likes us back and it gives us an affirmation about our beliefs. Another factor is *reciprocal affection*. If another person likes us, we tend to return the affection. Being liked by another person can even compensate for a lack of similarity. *Bodily attractiveness* is an important factor for attraction in humans. Experiments show that the emotional theory of cognitive evaluation, mentioned under "Adequate emotional reaction", is influencing the formation of loving feelings. If a person gets physiologically excited, regardless of the cause, and sees an attractive person, the excitation might get attributed to the other person and interpreted as love.

As mentioned in [AWA04, p.375-379], there are various theories about love. And it is also assumed that there is more than one kind of love, depending on the theory. The most basic one will be explained here. It divides between two kinds of love. The first is the *passionate love*. It is based on physiological excitement and desire for the other person. If the passionate love is returned it usually leads to fulfilment and ecstasy. If it is not returned it can lead to sadness and desperation. The second is *Companionate love* which is based on intimacy and affection without excitement or desire. This is a more settled and contemplative kind of love, which is for example shared between old people.

The expression of love can vary. In most cases a physical closeness is involved. Passionate love usually is initially indicated through looks and facial as well as bodily expressions. If the

love evolves, touching the others body, like kissing or holding hands is involved and can end in sexual activities. Also the verbal expression of love is important. For companionate love it is more important to be there for the other person. This includes being physically present as well as helping each other. The intimacy is based on sharing thoughts with each other. Physical closeness and joint activities are important for both kinds of love.

According to Laplanche [LP73, p.470-472] in psychoanalysis the object of the sexual drive, which is the source of love, is biologically not determined. The drive object is in this case a person. If the memories get cathected again because of one or more of the above mentioned factors, which influence love, a memory trace for the person and a positive feeling is created. If this gets associated with the sexual energy this might be the reason for love.

Aggression

As explained in the paragraph before aggression is part of Freud's last drive model. It is an outward directed representation of the death drive. Its main goal is to reduce the accumulated energy of the Thanatos, the energy of the death drive.

First a definition what aggression can be is necessary and which kind is to be considered further. As mentioned in [ST02, p.123-126] there are three different kinds of aggression. The fist is the *hot* aggression. Aronson [AWA04, p.440] describes it as "intended behaviour, with the goal to afflict other people with physical or psychic harm". This is what we usually regard as aggression. The second is *cold* aggression. It describes the aggression shown when hunting for food. Killing another animal in order to nurture from it is a violent act. But in this case the aggression is just a means to an end. Whereas in hot aggression the affliction of damage is the main intent. The third kind of aggression mentioned in [ST02, p.123-126] is *male dominance behaviour*. This kind of aggression is exclusively shown by male individuals to almost exclusively other male individuals of the same species. Here the intent is not to harm or kill the other individual, but to show the own dominance in order to win over the females of the group. In the following, only hot aggression will be discussed.

First the reasons for aggression shall be discussed. There are various factors which can be responsible for aggressive behaviour. A reason for aggression can be *pain* or more generally speaking if a person does not feel well. Especially if an animal feels pain and can not escape a threatening situation, it will inevitably attack. A more common phenomenon is that factors like high temperature, high humidity or loud noises can raise the disposition for aggression. Probably the best known reason for aggression is *frustration*, which occurs if an individual is prevented from reaching a goal. Additional factors can modify the aggression resulting from frustration. The closer to the goal we are, the more frustrating a hindrance can become. If the frustration is unexpected, it can enforce aggression. Other aspects which have to be considered are the size of the opponent. If size and strength of the opponent obviously exceeds the own strength and size, it may reduce the urge to directly express aggression to the aggressor. However this does not mean that the aggressive tendency goes away. If the frustration is understandable, legitimate and not intentional it may reduce the likelihood for an aggressive response. Also the relative deprivation, meaning the feeling that one gets less than he should or expects, in comparison to somebody else, can aggravate the situation. The last point is *provocation*. If somebody confronts us with aggressive behaviour, we often tend to respond in an equally aggressive manner. If the provocation is perceived as unintentional or not related to the own person it may not result in an aggressive response.

The first signs of aggression are usually an aggressive facial expression, an aggressive posture and gestures. This non verbal threat can be accompanied with verbal threats and intimidations. Finally the aggression can erupt in a violent act, which has the intention to verbally or physically hurt the other faction.

Psychoanalytically, the death drive is initially directed towards the own self and its destruction. But it can also be directed outward as aggression and the wish for destruction. If this energy gets associated with a drive object the aggression is focused and the individual might show a destructive behaviour towards this object or person.

Dynamic Group Finding

A group can be seen as two or more people who interact with each other and are dependent on each other. This means that their needs and goals influence each other. It is questionable if our tendency of joining groups is inborn. According to [JSH07, p.412-413] there are some theories why people are joining groups. The socio-biological theory states that groups provided better dealings with enemies or predators, better hunting or growing crops, more successful mate finding, easier childcare, easier exchange of information and division of labour. More details can be found for example in [Daw76, p.282-315]. The cognitive theory states that groups help building and verifying the own opinion, help define oneself through the group and get guidance for the behaviour. The instrumental theory says that groups are based on exchange of goods and help but also psychological "goods" such as love or friendship. These exchanges are easier over a long time if the individuals are in a group and help satisfying the needs of the individuals. Mann [Man99, p.50] states that joint problems enforce the cooperation among individuals. The cost-benefit ratio for being a member of a group is also important. If it is not satisfactory the member is likely to leave the group.

The basis for any group is a certain homogeneity. This corresponds to the similarity mentioned in the paragraph about love. People are drawn to groups which have a certain similarity with them. On the other hand does the group usually enforce the homogeneity of the members. This is done through some factors. *Social Norms* define the acceptable behaviour for a group, by setting up rules and laws. A breaching of the rules is usually punished by ostracism or ejection from the group. *Social roles* define expectations from the group, how the individual has to behave. These roles can vary from individual to individual. Meeting up to the expectations of the role is usually experienced as fulfilling. On the downside the social roles can extinguish individuality. Also not meeting up with the expected role behaviour is usually answered with disapproval. *Group cohesion* is the bonding within a group and enforces the sympathy within the group. If the group has to reach a goal a good performance increases group cohesion. Also the inverse is true, a high group cohesion increases the performance of the group.

Reichholf [Rei04, p.150-161] explains the group finding of humans from an anthropological point of view. Mothers and children were waiting in a secure place for the men to return with prey. The pregnant women and small children needed the nutrition, especially proteins and phosphor, which the men provided for the development of the children. In contrast men need fat and carbohydrates, as sources of energy for the search for pray, and only small amounts of proteins. In this way what one gender provides, is primarily needed by the other one. This nutrition and the women being able to let the men gather their food was a necessity for mankind to be able to develop a brain the size it is nowadays. Men provided the nutrition the pregnant mother needed for the child and supported the child in the first years of birth.

Freud [Fre21, p.73] said that other people are regularly present in the psyche of an individual as idols, objects, helper or enemy. If an individual joins a group the same object is placed at the position of the Ego-ideal which helps them to identify themselves with each other. On the other side this mutual identification of individuals is comparable to a relationship with sublimed sexual dimensions.

Hierarchy

Hierarchies, which are described in this section, and Specialization, which are described in the next, are not easy to separate. The simplest hierarchy has two levels with a leader at the top level and the group members on the lower level. Usually the leader of a group makes most of the decisions which can be seen as some kind of specialization. To separate the cases, this section is only concerned with the "pecking order" within a group.

According to Mann [Man99, p.55-56] the hierarchy of a group defines the authority and influence a member has in the group. If a group member has power over the means of need satisfaction of other members this individual has leverage over these other members. There are many possibilities what resources can act as leverage. The first is the control over goods, like food or sexual partners. They can be the direct means of need satisfaction. If one person controls large quantities of goods, he has the power to reward or punish other members of the group. Other sources of power are the possession of exclusive knowledge or of rare skills, which are useful for others. Also a role model, which is admired or imitated, has the power to influence others.

Mann [Man99, p.45-48] states that animals which are higher up in the hierarchy have a privilege, when it comes to the distribution of resources and sexual partners. If there is a lack of resources the hierarchy decides, who gets the most of the resources. This avoids fights which would probably have the same result. The purpose behind this is maybe to ensure the survival of the fittest in times of shortness of resources.

Among animals the winner of a conflict is usually determined through threatening gestures. The one who acts wilder, is louder or is bigger wins the fight without hurting the other one. Among humans conflicts are much more often solved through violence than among animals.

Power directly influences the status of the person in the group. A person with power can have many advantages. It can result in a high influence over the group and its decisions. This central position results in a high involvement in communication. Also the reward for powerful person is usually higher. Power usually has a positive effect on the self-esteem of a person. The involvement in activities within the group, the importance of the role concerning resources but also prestige and the power itself are contributing to the satisfaction a person feels.

In many hierarchies status symbols are developed. These can be badges on uniforms, big offices or limousines. Their main purpose is to show others the rank of the individual in the social hierarchy. This becomes more important in larger groups. Individuals often do not know each other and a quick visual indicator for the status is needed.

Hierarchies work best where explicitly defined actions have to be performed. If the lower levels of the hierarchy should be creative and respond quickly to situations a more democratic and team oriented approach is more useful.

In [Fre21, p.73] Freud stated that a leader loves each member of the mass equally like Jesus or a commander. If the mass dissolves, it leaves a feeling of loneliness. A leader is important for keeping the mass together but he can be replaced by an idea or a hostile feeling for an object.

Specialization

In the paragraph before, hierarchy within a group was defined as privileges in resource distribution. In contrast to that, specialization is usually connected to a hierarchy but not necessarily. The role an individual plays in a group can determine its status. In return, the position in a hierarchy can also determine the role the individual has to play and the tasks it has to fulfil.

Mann [Man99, p.59-61] explains that specialization means the division of labour or the fulfilment of a role within a group. The problems of everyday life call for solutions which are easier to solve if the group cooperates and divides the functions of the members.

If there is no structure in a group, which has to solve a problem, there are usually two roles which emerge. The first one is the leader who produces ideas and manages the interaction. He is mainly concerned with the solution of the problem. The other role is the social emotional specialist. He is a mediator which helps to solve conflicts within the group before they could lead to aggression. He also tries to help others if they need it and makes jokes and comments which relieve tension.

According to [Man99, p.45-48] the leader of a group of apes is an individual which makes the decisions for the group. If he decides to leave a place, the other group members will follow. Individuals higher up in the hierarchy are also the ones who are imitated. An individual higher up in the hierarchy rarely imitates a subordinated individual.

Adequate Emotional Reaction

According to [ZG04, p.547] emotions include and are influenced by physiological excitement, feelings, cognitive processes and behaviour reactions. They are an answer to a situation, which is perceived as personally important. The physiological background for emotions are reactions like high pulse, quick breathing and muscle tension. Among the cognitive processes are interpretation, memory and expectations relevant. The cognitive evaluation can in some cases interpret the experienced emotions. There are many theories about emotions and what counts as an emotion. But the four emotions which most theories agree upon are fear, anger, joy and sadness.

In [ZG04, p.556-557] the theory of cognitive evaluation is described. It states that two factors are necessary for the development of emotions. After perceiving a stimulus the physiological excitation, which is considered general and unspecified, is the first step. The second step is the cognitive evaluation which categorises the excitation and forms an appropriate reaction.

There are various functions which emotions have to fulfil [ZG04, p.557-561]. First they are the source of excitement and motivation. If we like something we want to acquire it. If we are afraid of something we avoid it. Second they have a social function. We keep distance from angry persons and we seek the company of smiling, happy people. If we feel good, it is more likely that we help other people. The same is true for the opposite, if we help other people we feel good. Third they influence cognitive functions. Emotions influence how and what we learn, our memory, our social judgements and our creativity. Memories and emotions are stored together.

For Freud affect was always linked to a presentation. Affect and presentation are cathected together but both can be handled differently. This shows that in psychoanalytic theory the connection between them exists but can be assumed as a loose one.

Stress

Stress is the reaction pattern of an organism to a stimulus, which disturbs its homeostasis and which strains or exceeds the organisms ability to cope with these effects. A stressor is the internal or external cause for a stress reaction. There are two different kinds of stress. Acute stress is only temporary and triggers the inborn fight-or-flight-reaction. Chronic stress is a continuous excitation, where the individual sees the internal and external resources not fit for coping with his situation.

The reactions to stressors are described by the general adaptations syndrome for chronic stress by Selye [ZG04, p.565]. There are three stages which the individual goes through when in stress. The *alarm reaction* is a short phase where the body prepares for energetic actions. If the stressor persists the body enters the phase of *resistance*. In this phase the body is able to resist the weakening effects of the stressor. If the stressor continues for too long or it is too intensive, the resources of the body are depleted and the body enters the phase of *fatigue*. A perpetual state of stress can weaken the immune system and the body becomes susceptible for illnesses.

In [ZG04, p.567-574] there are four typical stressor categories mentioned, which usually have typical reactions. *Big life changing events* can be either positive or negative. Positive changes can be a marriage, a child or a promotion. Negative changes can be an illness, the loss of a loved person or the loss of a job. In either case these changes can cause stress for the person concerned. The more and bigger the changes, the more susceptible the individuals are to infections and illnesses. The second cause for stress are *catastrophes and traumatic events*. If events are negative, uncontrollable, unforeseeable or ambiguous they can cause stress. Post-traumatic stress disorder is the perpetual reliving of the traumatic event in nightmares or flashbacks. It can lead to emotional dulling regarding everyday events and an estrangement from other people. Other symptoms are sleeping problems, concentration difficulties and amplified alarm reactions. These effects should wear down over time, usually in a couple of months. The third cause are *chronic stressors* which linger for a long time. In psychic stressors there is no clear line between acute and chronic stressors. For example, if a persons bicycle is stolen, this can cause acute stress. If this person from now on constantly fears that his bicycle might get stolen, it turns into chronic stress. Chronic stress can be caused by society or the environment. Examples would be overpopulation, high crime rate, bad economic situation, environment pollution, illness, terrorism or personal failures. The effects of chronic stress are usually depression and bad cognitive performances. The last and most common cause are *everyday problems*. These can be being late, loud environments, forgetting something or getting a parking ticket. The more everyday problems a person experiences the worse the corporal and mental health of the person becomes.

In psychoanalysis stress can be seen as the cathexis of a representation. For positive life changing events it will be with energy of the life drive. In every other case it will be with the energy of the death drive. This energy can provide the motivation to do something and is discharged through activity. If it persists and can not be completely discharged it will represent itself as stress, id est the motivation to do something but the individual is unable to do so.

Ability to Work in a Team

One important aspect of building a team is the ability to work together. Some tasks that may be necessary for surviving are easier or only possible if they are done in a team. A good example is hunting. Skyrms explains in [Sky01] the example of hunting a stag versus a hare. The hare can

be hunted alone but it brings less benefit of the hunt than the stag. The stag can not be hunted alone. So if a group wants to hunt the stag they have to cooperate. This is based on trust in the other team members that they will add their share. If they do not the effort of the participating team mates may prove fruitless. On the other hand if the cooperation fails they have to resolve to hunting hares which is satisfying but not as rewarding as their cooperation.

Another issue in teamwork is the possibility to scrounge for resources others had to work for. Experiments were conducted as described in [FG02] where people had to work together for a greater good, which costed them something like effort or money. It is expected that everyone, who benefits from it, to work for or put their share into it. If they do not, their behaviour is usually not tolerated. If their team mates have the opportunity to punish the deviant behaviour, they most likely do so. This even holds true if it costs the contributing members resources or effort. This makes sense insofar as it is more likely that the scrounging team member will be cooperating in the future when having to expect punishment. Thereby, the members of the group make sure that every member contributes to the success of the group. None should be able to only harvest the goods without efforts on his side. This would be a loss for all the other team members, which have invested in the goal but did not get something out of it. The result is, that this member is not trusted again and can even be evicted of the group. Another consequence of this behaviour is a game theoretical one. If everyone relies on exploiting the effort of others, nothing ever gets done and the whole group suffers.

The psychoanalytical background for teamwork is presumably a combination of the Super-Ego and the Ego. The Super-Ego tells the individual to keep to the social standards and not to break them out of a mood. The drives might want to persuade the individual to try to reach a smaller but also satisfying goal, which might betray the other team members. The Ego has now the obligation to mediate between the demands of the Id and the demands of the Super-Ego. It has also to take future consequences into account if the individual does not follow the role assigned by the team. In a successful joint effort it might be the demand of the Id to enjoy the success alone. But the Super-Ego might hint to the social demands and the self perception of the individual. The Ego might also consider the implications on future actions. The individual might get excluded and in the end is not able to participate in future success.

Behaviour During Conflicts of Goals

In [ZG04, p.385-390] it is explained that the basis for all decisions are judgements. Judgements are processes in which people form an opinion, draw conclusions and people and events are critically evaluated, based on available information. Judgements are usually based on heuristics. Usually not all information which would be necessary for an optimal decision is available. There are three basic kinds of heuristics. *Availability heuristics* ground their judgements on how easy information can be retrieved from memory. Moods can influence how easy information can be remembered. If we are in a good mood, memories which are associated with happiness can easier be remembered. *Representativeness heuristics* categorizes objects based on their characteristics and what characteristics are seen as representative for this category. *Anchor heuristics* use a starting value against which the value in question is compared. However, this starting value can be arbitrary sometimes.

As Damasio [Dam94, p.191-196] states we do not always resolve to logic when making decisions. When having to deal with uncertainties and complex personal and social problems they are not as reliable for decision making. As Damasio mentions in some cases however it might be

advantageous to not have emotions interfering with decision making. This might be the case in situations where a panic reaction could make the situation worse than a rational one.

What purpose a system serves, is often best observed, when it fails to work. In an example Damasio mentions a man, who has lost the ability to feel emotions. In dangerous situations, where a clear set of instructions was given to handle it, the man was able to master the situation without problems. In a specific situation the man was driving across a patch of ice on the road. Another person who panicked landed beside the road. This was a situation where his lack of emotions was an advantage. But another example showed that this man was not able to choose between two dates for a meeting. He considered all possible options and eventualities he could come up with. But he was not able to decide which date he would prefer.

This shows there are basically two extremes to make a decision. A rational one without involving emotions, and an emotional one which does not rely to much on logic. A rational decision is advantageous if only a few known factors are to be considered and a solution can be found based on these knowings. In dangerous situations emotions might provide the necessary activation but if the person panics, he might make decisions which are bad for him. The inclusion of emotions into the decision process is beneficial if not all factors can be considered or if a lot of factors are just of minor interest. In this case emotions can make a decision, which is not based on rationality but rather on feelings, much easier. Sometimes not everything should be considered but an unconscious decision what option is preferred can accelerate the process. The inclusion of rational considerations could extend the decision process enormously and could even prevent the individual from reaching a decision at all.

As mentioned in [EK03, p.483-486] there are a few factors which influence our decisions. If the decisions are easy the *utility* theory is sufficient. It takes into account the subjective utility of the outcome and its probability to attain it. The product of the subjective utility and the probability to attain it is the expected utility which should be a maximum. But most of the time the utility alone does not suffice to explain decisions. The theory of *loss aversion* states that for most people the avoidance of a potential loss is more important than a potential gain. A similar phenomenon is the *sunk cost effect*. This effect causes people to invest more resources in the attempt to save previous investments. People also want to justify their actions to themselves and to others. If they can not find a justification for an action they are likely to postpone it or not to take it. The theory of *anticipated regret* says that choices which are generally desirable but might be regretted in the future tend to be avoided. This anticipated regret can produce an *omission bias*. It states that if we have to make a very difficult decision where it is not possible to determine if one option is clearly better than the other one, we tend to avoid making a decision by staying inactive. Even if this would be the worse choice. Self-esteem also has an influence on decisions. If the self-esteem of a person is low, he will avoid risky situations, even if they are more profitable. In this case, choices which are a sure gain are preferred. They fear that threatening or negative events will further lower their self-esteem if they do not succeed.

Psychoanalytically the ego is the main location where the conflict takes place. First there are our drives, which produce wishes and urge us to satisfy them. This decisions are usually not rational. Also our emotions tend to produce preferences depending on our experiences with previous encounters. This involves our memories and what emotions are associated with the objects, persons and situations. And third the unit responsible for rational decisions is usually also involved and produces another option which should be pursued. This one is usually the decision which is influenced by what the ego thinks is right. It might get influenced by the

superego, which tells us what we should want. Also the distorted demands of the drives, which have been disfigured by the defence mechanisms, can influence our decisions.

Reciprocity

The theory of reciprocity states, that if somebody else does us a favour, we feel obliged to repay this favour. If we get a present, we feel inclined to return another present to this person. This reciprocity is independent of the sympathy we feel for the other person. Even if we do not like the one doing the favour we still feel the need to repay it. Cialdini [Cia97, p.45] among others states that the ability for reciprocity is the basis for becoming human. We achieved what we have because we were able to share food or competencies. Culture anthropologists see this as the basis for division of work. It might also be the foundation for exchange of goods and services. This makes people dependent on each other which in turn could have the effect of bringing individuals together to groups which share resources. If a person gave away something, he could expect to get something back, which of course lowered inhibitions to help or give something to others.

Not returning a favour or gifts strips the person of the mentioned advantages. This usually leads to being despised and avoided by other people. They are less likely to help in the future. The trust, that favours are returned, has to be re-established which can be hard.

This principle is very basic human behaviour and present in most individuals. It is most likely to trigger a reaction which is at least in its nature foreseeable. Based on this the theory of reciprocity a person could exploit this and manipulate another person. A person could do another person a small favour in order to request something he wants from the other one. This usually also works if the returned favour is connected to some trouble for the returning person.

The psychoanalytical function which is possibly most involved in reciprocity is the Super-Ego. The management of demands can tell the individual that it has to return a favour because that is what society expects and demands. Also the management of the Ego ideal might be involved since most persons want to perceive themselves as social and generous. Not repaying favours would be perceived as cheap and selfish by others. This would cause a difference by what the Super-Ego demands and what the Ego expects to perceive as a result of the individuals actions. The decision unit has also to take into account that any a reproach by others can make the attaining of a goal much harder if other individuals decide that they wont help him any more.

False Expectations

This behaviour is based on the principle of cause and effect. Everyone assumes that we live in a complex but after all deterministic world. Therefore if we take some action or witness something happening and the result is the same a few times in a row, we tend to see a connection between the cause and the effect. But the causes of the effect can be something very different than what is perceived by the observer. If the cause is something not observable for the viewer a false connection between cause and effect can be made. This can even happen after the first time this is witnessed. Also if only the effect is witnessed a person tends to search for an explanation. Usually something which is close in space and time is taken as the cause for the effect [EK03, p.78-79]. It is obvious that these perceptions of the cause for an effect are bound to be erroneous under these circumstances.

Bartlett [Bar32] was one of the first who brought *schemas* into the way we perceive things and expect them to behave and evolve. This theory says that prior knowledge and experience influences what we expect to find in similar situations. If a schema is activated by a clue, other parts, which form the schema, are also activated. These additionally activated informations form our expectations which are usually right if we have learned them and they have proven to be correct. But they may be occasionally be wrong, which causes us to take appropriate actions to correct the situation [EK03, p.352].

In [EK03, p.78-79] an example is given, that people tend to perceive a causality in the movement of two figures if one stopped its movement and the other one started at a slower rate as if the first had caused it to move. The effect it had for the perception was unaffected by the nature of the two objects. This represents the physical principle of passing on the kinetic energy if a moving object hits another. But in this case the interaction of these objects was purely virtual.

Psychoanalytically the perceptions are involved at the beginning. These are the basis for all cause and effect assumptions the individual has. The rational part of the brain now creates connections between two events if they seem to influence each other. These assumptions are then stored in memory. If one of the factors is experienced the memory produces the rest of the effect chain. The reality testing now ensures that the other factors which are assumed to be involved are actually present.

Consistency

A person acts consistent if his reaction is in general the same in similar situations. Usually there is a behaviour pattern, which decides how we react in certain situations. Very basic patterns, like for example fighting or fleeing, are inborn. Other behaviour patterns, which are more complex, have to be learned. In psychological literature there are basically two theories which deal with the consistency of behaviour.

The first theory which is concerned with consistency is conditioning. The effects of *classical conditioning* were first described by Ivan Pavlov [Pav27]. It is natural that an unconditioned stimulus shows an unconditional response like the salivation of a dog in response to food. Pavlov now showed that comparing the unconditional stimulus, namely the food, with an conditional stimulus, namely a ringing bell, still produced the unconditional response of salivation. The interesting result showed when, after some time of presenting unconditional and conditional stimulus together, only the conditional stimulus was presented, the dog still salivated. This is called a conditional response. The *operational conditioning* is associated with the name B.F.Skinner. In his boxes he showed that, within physical limits, an animal can learn new behaviour. For this he used reinforcement, enjoyable results, or punishment, results that the individual wants to avoid. This can happen in positive form, adding something enjoyable or threatening, or negative, taking it away. Herkner [Her93, p.28-33] explains if the behaviour is continuously (id est every time) rewarded it is learned much faster but can also be extincted faster. On the contrary if the behaviour is rewarded intermittently (id est not every time) especially if it is done with random intervals between the rewards, it is learned much slower, but also shows much more resistance against extinction.

The other theory which is associated with the consistency of behaviour is the theory of *cognitive dissonance* by Leon Festinger [AWA04, p.188-190]. This theory says that two cognitions a person has which contradict each other cause a tension or a feeling of unease within this person. In

case this contradicting cognitions include our self perceptions the feeling of unease is perceived as especially unpleasant. If how we see ourselves and what we do are not consistent with each other, we try to reduce this inconsistency. This can happen in three ways. First we can change our behaviour to make it more consistent with the believes of ourself. Second we could change one of the cognitions, maybe by saying that it is not true. Or third more cognitions which are consistent with one of the cognitions can be added so the other side seems minor and ignorable. Interesting is the first one of these points. Herkner [Her93, p.34-36] mentions the commitment of the dissonance theory. This describes how easy it is to change behaviour, a belief, an estimation etc. If a cognition is public, meaning that many people were able to witness this specific cognition a person has, or it has been shown often to others, it gets harder to change. This influences which cognitions are likely to change and which are not. Also a cognition which has many consonant relations is very unlikely to change since they would become dissonant and would cause a lot of discomfort.

The first theory shows that learning influences if a behaviour is picked up, which will continue for a while. Maybe even after the purpose of this behaviour has ceased to exist. The second theory shows that what we believe in also influences our behaviour. And that after we showed this behaviour, we tend to keep it up. Especially if other people were able to watch it.

What has additionally to be considered, is the step from one special case to other similar cases. Living beings are usually able to react to similar situations in a similar manner. This is called *generalisation* [ZG04, p.251-252]. The more similar the stimulus is to the first learned stimulus, the stronger the reaction to this stimulus will be. A predator emitting a slightly different sound than the known sounds, will still be recognised as a predator with the according reaction. The opposite to generalisation is *discrimination*. If a stimulus has only a few similarities with another one, they should not be confused. It would not be wise to flee from an individual, which has only a shallow likeness with a predator. To work properly, generalisation and discrimination have to be in balance. The individual should be neither overly reactive nor overly selective.

Psychoanalytical consistency is based on the principle of facilitation. If something is done a couple of times and it gets rewarded it will be associated with positive emotions. This helps cathecting the neurons involved in the behaviour and it is more likely to be done again in the future. The more often this behaviour is executed, the more the facilitation makes it easier to do it again. If on the other hand two memory traces are inconsistent with each other, they may try to inhibit the activation of the other one respectively. The commitment refers to the activation of associated memory traces which are not easy to discathect.

3.2 Use Cases

In this section the requirements described in Section 3.1 are analysed and put into use cases. Each of these cases will be explained in detail. This explanation will be the basis for the test cases, which will be defined in the next Chapter 4.

The explanation of the use cases will include a textual description. The involved actors are described especially if there are more than one and if they are interacting with each other. If a use case is referring to another use case either by being the basis for or a possible extension of another use case this will be mentioned. The reasons and preconditions for a use case will be listed. Some functions will be necessary for all use cases, like perception or motor functions. These will not be mentioned explicitly. The normal expected flow of the action will be described

as well as possible alternatives. It has to be mentioned that the flow of a use case is not to be understood as in a normal software project. When speaking about behaviour only a rough estimation of action and response can be given but not a detailed step by step list of actions. If an explicit result of the action or interaction is expected this is also mentioned.

It has to be mentioned that behaviour can not be predicted deterministically. Various factors are influencing every single decision a person makes. If he acts rationally, the behaviour is the same for most actions and might be more likely be foreseen. But as soon as emotions get involved it becomes hard to predict anything. Emotions and moods influence behaviour in a way, which makes it hard to determine. Why someone has made a decision the way he did or the reasons for an action are often not obvious. In the same way this presumably makes it hard to foresee any reactions of a virtual individual with behaviour similar to humans. We can only make assumptions how a Bubble will react to a certain situation or stimulus. In the following the behaviours which are most likely for a situation are listed. But it might as well be that a completely different reaction will occur.

3.2.1 Love

The three causes for love which will be considered here are closeness, similarity and reciprocal affection. This can either lead to passionate love or companionable love. Both kinds of love have different characteristics. For passionate love the satisfaction of the sexual drive through displays of affection is important. For companionable love it is more important to receive help and understanding. In both cases a physical closeness is the result. Physical excitement might be a key to develop loving feelings for another Bubble. This excitement can have another source but will get attributed to him if he does not have a negative connotation.

Actors

For this the usual case of a relationship is assumed which consists of two individuals. For both kinds of love, passionate and companionate, two Bubbles who are involved in this relationship are considered.

Precondition

The Bubble has to have a sexual drive and the possibility to cathect the mental object of other Bubbles with its energy. This requires modules which handle the drives and affects on the one hand and the memory and the presentation of the other Bubble on the other. Physically he also has to have the possibility to show its affection. Also the possibility to relieve his tension, for example through kissing, is necessary.

Course of Action

1. A trigger for the possible increase of affection for another Bubble is perceived. This will probably take some time until the effects take place. Of the four factors which were listed in the requirements the physical attraction will be omitted. It might not be possible to determine the aesthetic perceptions of a virtual being for at least the next few decades.

   (a) If two Bubbles are in the vicinity of each other for some time they may start to grow affectionate for each other. The vicinity may be understood as within the sensing range. The time they have to spend near each other does not have to be consecutive. There may be times where they leave the sensing range of the other Bubble. If they enter the range again after some time the effect might start to work again. In either case the effect of closeness is not instant but has to take place over some time.

   (b) If a Bubble has a similar set of believes, motivations or goals he can feel accepted in his attitude and grow fond of another Bubble. The problem here might be to observe these internal factors for other Bubbles as well as a human spectator.

   (c) For reciprocal affection a Bubble has to show some kind of affection for another Bubble. This will most likely happen in a physical way, kisses for example or presents.

2. Shortly after they became accustomed to each other they will be exposed to a situation where they will be emotionally excited and/or they have to physically work hard for something. This will cause a physical excitement which will be attributed to the other Bubble.

3. The effect will be a reciprocity of the behaviour. As well as the behaviour of the first Bubble, the behaviour of the second will continue over some time.

   (a) The second Bubble will stay close to the first Bubble. This is the reciprocity of the second Bubble for the closeness of the first.

   (b) The second Bubble will return the display of affection.

Alternative Flow

1. The Bubble does not necessarily have to respond with affection.

   (a) The second Bubble can be completely unaffected by the display of affection and the vicinity of the other Bubble.

   (b) If the Bubble has an antipathy against the other Bubble, it might have the opposite effect. The vicinity or even the showing of affection will rather amplify the negative feelings the second Bubble is having towards the first.This might lead to aggression towards the first Bubble.

Result

The Bubbles will search the vicinity of each other. They will mutually show signs of affection. If they have to leave the other one they will get unhappy.

Notes

This can even have a self-energising effect. The more a Bubble is in the vicinity of another Bubble the more he likes the other one. And the more he likes him, the more he wants to be in the other one's vicinity. Another point is that closeness and affection can get so important that other necessary things like nutrition can get neglected. The reciprocal affection may be the result of an unconscious reciprocity effect as described in Section 3.2.10.

3.2.2 Aggression

The three most common factors, which can evoke aggressive behaviour are pain, frustration and provocation. In case of pain he can be injured or in a state of unease caused by external or internal factors. In case of frustration he can work for something and anticipate a successful outcome, which is unexpectedly denied. In case of provocation the Bubble is verbally or through aggressive actions of another Bubble encouraged to show aggressive behaviour himself. The result can be that the Bubble flees, whether he is injured or not, or that he can die in a fight.

Actors

For these scenarios at least one Bubble is needed for showing aggressive behaviour. One or more Bubbles can be the source of pain or frustration. Provocation has to originate from another Bubble.

Preconditions

The Bubble has to have a death drive or an equivalent for aggressive behaviour. The decision unit can either be involved if the aggression is used as means to an end. Or its rational decisions have to be disabled if the quantity of the affection becomes too much. As a result the Bubble has to have the physical ability to assault another Bubble in order to relieve the energy of the drive.

Course of Action

1. The Bubble is experiencing a trigger which causes him to react in an aggressive way.

   (a) Aggressive behaviour through pain can be triggered in two ways. The first way is when the Bubble is hurt through the aggressive behaviour of another individual. The second way is the feeling of unease. This can be caused by anything which caused discomfort. An external cause can be a too high temperature. Internal causes can be hunger or thirst.

   (b) If the Bubble is expecting to reach a goal and fails to do so he can respond with aggressive behaviour caused by the frustration. For example he can go towards an energy source but shortly before he reaches it, it is taken away by another Bubble, which he did not see.

   (c) The third trigger for aggression is provocation. This requires another Bubble, which shows aggressive behaviour or verbally encourages him to attack.

2. The Bubble is responding in an aggressive way. Both points mentioned can occur independently or in succession. Usually the opponent is first threatened and if the threats were not successful he gets assaulted.

   (a) The Bubble can show verbal aggression or aggressive gestures. This can be an attempt to intimidate the aggressor in order to put him off from attacking by showing him that the Bubble is able to defend himself.

   (b) The Bubble can physically attack an opponent or in case of frustration an object. This will usually result in mutual attacks.

(c) The Bubble can flee. If this is not possible and the Bubble is fearing an attack from another Bubble he will chose one of the options above.

3. In either case of point 2 the result can be one of three cases. If the reason for the aggression is another Bubble all of these are also applicable for the opponent.

   (a) In case of a fight or an injury it can lead to the death of the Bubble. This case is primarily applicable for conflicts with other Bubbles.

   (b) The Bubble can flee if he is about to lose the fight. This case is applicable to all reasons for the aggression if he decides to evade the situation.

   (c) The Bubble can stop the aggression and resign himself to the situation without necessarily leaving the scene. This is not applicable if an opponent wants to continue a fight.

Result

If he is fleeing the result will be his change of location. This must not include a change of situation if the reason for his aggression persists. If he had a fight, the Bubble is probably wounded.

3.2.3 Dynamic Group Finding

It is difficult to determine if Bubbles are joining a group. Probably the most simple reason to join a group is giving them a place where they can live together. Later a threat is introduced which they can only master together. Various other problems which they can master in a joint effort or alone should determine if they are working together.

Actors

At least two Bubbles are needed to form a group. On the other hand they should not become too many and form more than one group which may make the distinction among those difficult.

Preconditions

The Bubbles must be able to respond to the effect of closeness or similarity. Maybe the use case love can be a precondition for this use case, if the sexual dimensions are sublimed. They have to have an Ego-ideal which the group can fill. They also have to have the cognitive ability to realize, that their chances to master a threat increases if they work together.

Course of Action

1. Some Bubbles are placed in an area where they can live for a while. It should contain enough resources and do not cause them too much trouble.

2. A threat is added to the scenario. For example this could be a group of predators.

3. The Bubbles respond to the threat.

   (a) If the work as a group they should take some actions together. Either they are fighting the enemies or fleeing together.
   (b) A Bubble can ignore what the other group members are doing and take his own actions.
   (c) Some can face the threat and some can avoid it.

4. The outcome of the actions for the Bubbles depends on what they have done.

   (a) If they work together they can handle the threat. This should convince them that working in a group can be advantageous.
   (b) If a Bubble can make a different choice than all the others. He will either be excluded from the group after they face the threat or he will get hurt or killed if he faces the threat alone.
   (c) The more Bubble are facing the threat the easier it is for them to handle. If there are too few they will not be able to handle it and suffer the consequences.

5. A task can be presented to the group. For example this could be a shortage of energy and a large energy source is introduced which can only be accessed by the whole group.

Alternative Flow

1. The Bubbles must be able to procreate through two different kinds of gender. Each of the genders has to rely on the other for nutrition.

2. Both genders have to have an inborn interest to keep their offspring alive. Both should feel the need to care for them during pregnancy and the first time after birth of the child.

3. The females of the Bubbles are responsible for the birth of a child. During the time of pregnancy she is progressively constricted in her ability to gather required nutritions for herself. They are able to provide food for the males however. They can spend the rest of the time in a secure place, a home for the Bubbles, where they can wait for the male Bubbles to return.

4. The males of the Bubbles provide the food for the females and the children. They would be able to provide themselves with the required food. But the interest in the development of the children drives them to provide mother and child with the food they need. This happens in exchange for the food they need, which they get from the female Bubbles.

5. The child is not able to survive during the first time after birth. It is still dependent on its parents regarding food and security from dangers.

6. After birth both parents, and possibly other members of the group too, still care for the children. This caring for the children has to be inborn if the children should survive.

Result

After this scenario the group should try to handle a problem together, which can not be accomplished by one Bubble alone.

Notes

If a Bubble makes a different choice when the first task for the group arises, he will likely not participate in further group actions either.

3.2.4 Hierarchy

In order to show if a hierarchy is present in a group, they are given only a small supply of resources. These resources should only suffice for some of the group members but not all. According to theory, some of the group members will survive or benefit from the resources while the others die or get very little or none of it. If there is no clear hierarchy established at that point the members of the group will start to fight.

Includes

In order to have a hierarchy the Bubbles must form a group. Therefore it is necessary to either check if they have already formed a group or to predefine a group as described in Section 3.2.3. The possible presence of a leader, as explained in Section3.2.5, can also influence the distribution of the resources. He will likely get most of them and might even distribute it among some of the group members if he does not keep it all for himself.

Actors

For a hierarchy a group of Bubbles is needed. It can work with two Bubbles, but for a clear pecking order four or five would be preferable.

Preconditions

The Bubbles have to have an Ego-ideal which a superior individual can fill. Also demands and restrictions concerning the respect for the superior individual have to be present. In some cases the superior can be the focus of the defence mechanism of an individual. Additionally the population could have to have the survival of the species as a top priority. If all the individuals try to gain access to the resources they will fight, which will result in the death of some of them. If they share the resources they will not have enough for all to survive.

Course of Actions

1. The Bubbles have to form a group. This can be predefined or they can establish it on themselves over time.
2. The group is presented with a shortage of resources. This can be anything the Bubbles need for their living or well-being. Examples would be energy or sexual partners.
3. The group has to define a pecking order. This will decide who gets the resources and who does not. This can happen in different ways.
   (a) They can try to intimidate each other. This is done by showing aggressive behaviour but not attacking the other one. The one who gives in first is lower in the hierarchy.

(b) They can fight over the resources. This will also decide who gets access to them and establish a hierarchy, supposing the inferior survives.

4. If the resources are distributed in favour of the higher group members, they will have more supply. If there is an energy shortage they will survive longer than the inferior group members.

Result

In times of resource shortage there will be unequal distribution among the group members. The superior members will get more of the resources while the inferior get less or none.

Notes

Fighting over rare resources is a weaker strategy than establishing a hierarchy. For the inferior it will cost him the access to the resource. But the superior will also have to invest energy in the fight. Therefore, if there is a shortage of energy, the fight will have made survival for the superior harder as well. If a hierarchy exists the superior individuals will have a higher chance of survival, since they do not have to fight. It may take a natural selection to eliminate the fighting scenario from the behaviour repertoire.

3.2.5 Specialization

The task of specialization can mean two things. On the one hand it means the development of a leader. He is the individual in the group who decides what the group does. If he moves to another location in the world, the group will follow him. On the other hand it means that some individuals specialize on different roles or work than others. This means that if they have some options to reach a goal, they will in most cases prefer one way over the others. In some cases they will need to help each other or exchange the goods of their work.

Includes

In order for s specialization to make sense the Bubble must be part of a group. This can be a predefined group or it can happen through dynamic group finding as described in Section 3.2.3. Since two or more Bubbles are carrying out work whose result is shared with other Bubbles they have to have an exchange of goods or services so no Bubble is exploited. Therefore they have to have the ability of reciprocity as mentioned in Section 3.2.10.

Actors

The Bubbles have to have an Ego-ideal which a leader can fill. Also demands and restrictions concerning the respect for the leader have to be present. In some cases the leader can be the focus of the defence mechanism of an individual. A group of Bubbles like the ones mentioned in Section 3.2.3 is necessary if specialization should work. He could get pleasure out of what he is doing which causes him to practice his skill. This requires a drive, a memory for training and the affects associated with the work.

Precondition

It must be advantageous for a Bubble to specialize in a task and repeatedly do it again. This can be done to create a surplus of goods and trade them with the other Bubbles. The Bubbles have to have the rational ability to realize this fact.

Course of Action

Forming of a group member as the leader of the group:

1. The group is presented with two goals which are both attractive for the group to acquire.
2. The leader of the group decides which of the goals is to be pursued. He tells the group members what they should do.
3. The members of the group decide individually what they will do after they know what their leader decided.
   (a) They can follow his decision. This would mean they act together in pursuit of the goal.
   (b) A Bubble can decide that he would prefer to ignore the leader and take his own actions.
4. The group decides what to do after the actions.
   (a) Everyone which has worked together will participate in the reward. The leader is probably getting more out of it or is deciding who gets what out of the reward.
   (b) Everyone who did not follow the instructions will have to take the consequences. They will not get their share of the reward and are likely to get expelled from the group.

Specialization among the members of a group independent of a hierarchy:

1. Various diverse needs and their means to fulfil them are introduced. These means of fulfilment should be able to be prepared by one Bubble and consumed or used by another.
2. The Bubbles have to coordinate who carries out which task. Personal preferences or skills can become important here. Maybe the existence of a leader who coordinates the work is of advantage.
3. The Bubbles repeatedly carry out the task to get the goods or doing the service for other. The only occasionally or never care for other tasks.
4. The Bubbles exchange goods or services with other Bubbles. Through the exchange they get the goods or services they lack to fulfil their needs.

Result

All Bubbles specialize on only a small number of tasks of those they need to fulfil their urges. The other necessary tasks are carried out by other Bubbles and the results are exchanged among them. A leader in the group decides in cases of conflicts what goal the group should pursue.

3.2.6 Adequate Emotional Reaction

The emotional reactions of the Bubbles in various situations is to be tested. It is of interest if the Bubbles respond in an emotional way to the situation and if the emotions expressed are fitting. If the Bubble shows no or wrong emotions this can have severe consequences on his psyche or his life.

Actors

Basically only one Bubble is needed who is tested for his emotional experiences.

Preconditions

The basis for any emotion is a physiological excitement resulting from a drive. The Bubbles have to be able to feel affects like fear, anger, joy and sadness. Physically they have to have the ability to express their emotions in a physical way.

Includes

Since the emotion anger is a prerequisite for aggression the according use case covers the tests for anger. The use case for love is a good starting point for the testing of sadness when the Bubble looses a loved Bubble as described in Section 3.2.1.

Course of Actions

1. The Bubble is presented with various situations. For each emotion at least one situation is created to test their response.
   (a) For fear the Bubble is presented with a dangerous situation. It should be obvious to the Bubble that he will not be able to handle this situation.
   (b) For anger tests see Section 3.2.2.
   (c) For the tests of joy the Bubble is presented with an unexpected gift, help in a difficult or dangerous situation or the meeting of a friendly Bubble.
   (d) In order to test sadness it is convenient if the Bubble feels affection for another Bubble as described in Section 3.2.1. The loved Bubble should then leave or die in order to evoke sadness in the first Bubble.
2. The Bubble now reacts to the situation. His reaction can be adequate, he can show no reaction or an emotional pattern which is not normal or fitting in this situation.
   (a) If the Bubble is in a dangerous situation he will most likely show fear. This would result in fleeing or hiding if he can. Otherwise he will attack if possible.
   (b) For aggressive reaction see Section 3.2.2.
   (c) If the Bubble receives a gift or is together with a Bubble he loves he will show joyous reactions. This can lead to an increase of activity.
   (d) If the loved Bubble is gone the first Bubble will show signs of sadness or depression. A decrease of activity can be the reaction.

Result

If the Bubble is able to respond adequately to a situation, he can take appropriate actions to deal with it. Otherwise he can get into trouble or even get hurt or killed.

3.2.7 Stress

The four reasons for stress are life changing events, catastrophes and traumatic events, chronic stressors and everyday problems. The results depend on the kind of stress. They can be a weakened immune system, a decreased social life and emotional reactions like depression. He can also act aggressive if the Bubble sees it as a feeling of unease as described in Section 3.2.2.

Actors

The number of actors can vary. If the stress is caused by something in the environment only the Bubble experiencing the stress is present. But also one or more other Bubbles can cause stress for a Bubble.

Preconditions

The Bubble has to be able to put himself into a state of elevated readiness. This will happen when a drive is cathecting energy with a presentation in the memory. This can be associated with positive or negative affection. The attention is focused on anything associated with the objects causing the stress. This is helpful in a dangerous situation. But if it continues for a longer time his body will suffer from it with illnesses.

Course of Action

1. The Bubble is experiencing a situation which emotionally upsets him. As mentioned before there are four possible factors which can cause stress.

   (a) For a Bubble a negative life changing event can be the loss of another Bubble he loves (see Section 3.2.1). Another one could be getting expelled from a group. Positive events would be finding a Bubble he loves or joining a group.

   (b) The Bubble experiences a catastrophe or traumatic event. This can be an earthquake, the loss of a loved Bubble, or an unexpected attack.

   (c) Chronic stressors are usually caused by the environment. For example a perpetual threat or an unpleasant environment.

   (d) Everyday problems are small mishaps or troubles from the environment. These can lead to frustration. If a number of frustrating events occur they will cause stress in the Bubble.

2. The response for each of these stress factors varies depending on the factor. What they all have in common is that an alarm reaction prepares the Bubble to take some action. This is especially the case for traumatic events, where the Bubble tries to respond to a situation.

(a) For life changing events, the Bubble's immune system is weakened gets more susceptible for illnesses.

(b) If the Bubble has experienced a traumatic event, he might show decreased emotional reactions to situations. He also might reduce his contacts to other Bubbles. Other effects could be sleeping problems or increased alarm reactions.

(c) Chronic stressors can cause aggression and depression. For example through the frustration of not being able to deal with them.

(d) If the subjective amount of everyday problems exceeds the positive events, the result is a weakened immune system.

3. In some cases there can be longer lasting effects of a stressful situation. This is the case especially for traumatic events. If the Bubble perceives something similar to a stimulus associated with the traumatic event again, he might react with an alarm reaction. This might even be the case if it is unnecessary or inappropriate.

Result

For life changing events and to much everyday problems the Bubble will become ill. If he has experienced a traumatic event he will avoid other Bubbles and be cautious and jumpy. Chronic stressors can make the Bubble aggressive or depressive.

3.2.8 Ability to Work in a Team

There are basically two factors which determine if a Bubble is able to work in a team. First he has to participate in a joint effort to reach a goal and not pursue his own goals. Second he has to share the reward with the group if they had participated in the process of attaining the reward. If he does not participate in the effort or does not share the reward, he is most likely to be expelled from the group.

Actors

For this use case a group of Bubbles is required. Basically a group of two Bubbles suffices but more are also possible.

Preconditions

The Bubble has to be member of a group as described in Section 3.2.3. He also has to have a Super-Ego to know the demands and restrictions he has to obey to be part of the group. But it could also be his decision, not to follow them. This can be either through a drive, which influences his decisions, or it can be a rational decision.

Course of Actions

1. First the group has to have a goal which can only be reached together. An example would be the hunting of a large animal as an energy source.
2. The group has to work together to attain this goal.
   (a) The Bubbles can come to the conclusion, that the result of working together will be a bigger reward. This will lead to a joint effort of the Bubbles.
   (b) A Bubble might want to abandon the others and pursue his own goals. This may happen despite his affirmation of cooperation.
3. The group shares the reward of the effort.
   (a) Everyone who has participated has the right to get a part of the reward. Maybe a Bubble who had invested more can have a larger part of the reward.
   (b) If a Bubble does not want to share the result of the joint effort of the group is will probably get expelled from the group.
   (c) A Bubble who did not join the others in their effort will not get a share of the reward. He might even get punished or expelled form the group.

Result

If all work together, the group is able to obtain a goal which would not be reachable for a single Bubble alone. If a team member is not contributing to a success, he will be denied the earnings. If one Bubble refuses to share the joint earnings, he will get expelled from the group.

3.2.9 Behaviour During Conflict of Goals

The Bubbles ability to make decisions can be tested for various mechanisms. The focus lies on the theories of utility, loss aversion, sunk-cost effect and omission bias. The tests try to determine which choice the Bubble makes in different situations. It is also of interest if the decisions are rational or if he uses emotional reactions, which are similar to human reactions. Emotional reactions are useful in many situations but can be faulty under certain circumstances.

Actors

One Bubble is required for making the decisions. Other Bubbles are optional and can be part of the setting.

Precondition

The psychic entities which can produce conflicts have to be present. These are the Super-Ego, the Id and the Ego as a mediator between reality and the other two modules. The Bubble has to be able to evaluate situations to judge what he can gain from pursuing a goal. He has to be able to rationally decide what choice is the more economic one. He also has to be able to consider the risks of his actions and include prior investments in his calculations. Also drives, affections and memories can influence the decisions of the Bubble.

Course of Action

1. The Bubble is given two or more choices among which he needs or wants to chose. As described above there are various kinds of possible mechanisms which can influence the decision. The mechanism of justification was omitted since it is not possible to know by the agents behaviour if he has found a justification or not.

   (a) In order to test the utility mechanism the Bubble is presented with the choice between two options. For example the choice between an energy source which is easy to attain and one not so easy. It can be tested, to what extend the size of each energy source and their ratio to each other influence his decision.

   (b) Loss aversion says that the Bubble should be more afraid to lose something than being eager to gain something from an action. In an extreme example he should avoid an energy source which is surrounded by enemies. In a more simple case an energy source which is able to defend itself, id est a huntable animal with claws or fangs.

   (c) To test the sunk cost effect, the Bubble has to invest some resources into attaining a goal. On his way he is presented with new obstacles. At that point it would give him no profit if he pursued the goal further. It could even cost him more than he could gain.

   (d) The omission bias can be tested if the Bubble has to chose between two optional choices. Both of these choices can have a negative consequence for the Bubble. The worse consequence however would be not to do anything. The theory of anticipated regret states that he will avoid both choices if he can or prefer to stay inactive.

2. Depending on the choices the Bubble has to make a decision. These can be rational decisions, which humans occasionally take, or emotional, which humans tend to prefer. As mentioned in the requirements, it would be interesting to test the influence of the self-esteem of the Bubble on his decisions and his willingness to take risks.

   (a) The utility theory states that the Bubble should go for the easier, more rewarding goal if possible. Otherwise he should calculate the effort and chose the other option if the first seems not rewarding enough for the effort.

   (b) According to the theory of loss aversion the Bubble is not likely to take a risk if he might lose something in the process. He is more likely to abandon a goal in this case.

   (c) The sunk cost effect requires the Bubble to invest something in order to obtaining a goal. After his investment he is presented with further obstacles which make his efforts pointless. Alternatively he could even get less out of his actions than he has to invest. According to the sunk cost effect he will further invest in his plan to justify his initial investment.

   (d) For the omission bias theory, the Bubble is presented with two choices. Both ot them possibly have negative consequences. But not doing anything would be the worse decision. According to the theory he will still remain inactive in order to avoid being the cause for negative consequences.

Result

In this case the result depends on the setting. The Bubble can either take a rational or an emotional decision or he can make no decision at all. The Bubble will only profit from the

situation if the is able to make the right decision.

3.2.10 Reciprocity

If a Bubble is getting a present or help from another Bubble, he will feel the obligation to repay the favour. This can in turn be, by making a gift to the other Bubble or by helping him out in case he needs it.

Actors

In its simplest case there are two Bubbles involved in reciprocity. The first Bubble is initiating the process with his actions. The second Bubble is trying to repay the favour to the first Bubble.

Preconditions

The main module concerned with reciprocity is probably the Super-Ego. The demands tell the Bubble that favours or gifts have to be reciprocated. Also rational decisions can be involved. If the Bubble foresees that not repaying the other Bubble will result in no more help from him. He also has to keep in memory who has done him a favour so he can repay him and who is trustworthy enough to help him. A drive which urges him to help other, can possibly result in a rather altruistic stance which will be positive for the population.

Course of Action

1. The first Bubble is doing the second Bubble a favour.

   (a) The first possibility for a favour can be a present. For example the first Bubble can give the second Bubble some energy.

   (b) The second possibility is if the first Bubble helps the second Bubble. This can for example be gaining access to a food source which the first could not have done alone. Another example would be the help against an attack from an opponent.

2. There are two possibilities how the second Bubble can respond to the favour of the first one.

   (a) The second Bubble now feels the need to return the favour. The possibilities for returning the favour are the same as in point one. But a present does not necessarily mean that the favour has to be repaid through a present. It can also happen through helping the other Bubble. This is also applicable vice versa.

   (b) The second Bubble is not returning a favour or a present. This will probably cause the first Bubble to feel exploited. The first Bubble will restrain from giving the second Bubble something or helping him in the future.

3. It is likely that this exchange of help and goods will continue if both parties are certain, that their generosity will not be exploited.

Result

The first result is the exchange in help or goods. The other results are rather internal as the Bubbles are more likely to like each other. But also the likelihood that one of the Bubbles is doing the other one a favour is increased.

Notes

The repaying of a favour is restricted to the Bubble doing the favour. Repaying the favour to another Bubble will not be regarded as a valid repayment. The first Bubble who did the favour will not have any profit from the interaction.

3.2.11 False Expectations

False expectation can be the result of a perception, where the virtual cause and effect are not really linked to each other. He could also be used to do something in a certain sequence. But suddenly something is missing or is not working out as he expects it.

Actors

One Bubble is needed who is experiencing something in the world and drawing wrong conclusions.

Preconditions

The Bubbles have to have the necessary organs for perceiving an action in the world. This might require that the attention of the Bubble is focused on this action. From this perception he has to draw rational conclusions and apply them to reality. From this a mental pattern is created, which represents what happens in the action sequence, and stored in memory.

Course of Action

1. The Bubble perceives an sequence of actions which seem to be causally linked. Their occurrence is purely coincidental however.

2. He expects now that this chain of action is occurring every time he perceives one part of this chain.

3. He can act now on his beliefs but can come to a completely different result. Alternatively he could come to the same result but his belief of the cause can be completely wrong.

Result

The Bubble is either not getting the desired result or his actions are meaningless for the result whether he reaches his goal or not.

3.2.12 Consistency

First a behaviour has to be learned. This usually happens through reward and punishment. When it is learned it is more likely that in certain situations this behaviour will be shown again or avoided. Later the behaviour is kept up or changed depending on the believes of the Bubble and its environment.

Actors

Generally only one Bubble who's behaviour is of interest is needed. But many situations can also involve other Bubbles.

Preconditions

The Bubble has to have a memory system, which enables him to remember similar scenarios. This includes responses to them, if the perceived outcome for him was positive or negative. They will get associated with the scenario and will make him want to do it again. The primary process will want to repeat positive effects and avoid negative ones.

Course of Action

1. In a certain situation the Bubble sets an action. The kind of action is not important since every action can be enforced or suppressed.
2. The environment or another Bubble produces a feedback for the Bubbles action. There are two possibilities for a reaction.
   (a) The result is pleasant for the Bubble. This will enforce the action and he learns to do it again.
   (b) The result is unpleasant for the Bubble. The Bubble learns that this result is not beneficial for him, which will make him restrain from doing it again.
3. Depending on the feedback the Bubble got the first few times, he will continue this behaviour if it was pleasant or avoid this behaviour if it was unpleasant.
4. If the Bubble finds out that his behaviour is not compatible with his belief he might change it to reduce dissonance.

Alternative Flow

1. The Bubble is presented with a stimulus. This stimulus has to have some characteristics which the Bubble can perceive and distinguish the stimulus from others.
   (a) The stimulus can be dangerous or unpleasant. A dangerous stimulus can be a predator which can have a frightening look or make dangerous sounds. An unpleasant stimulus can be a some poisonous food, which can have a certain colour or smell.
   (b) A pleasant stimulus can be something good to eat. This can also be discriminated by looks, for example through colour, and smell.

2. The Bubble can learn after a few encounters what is good and what is bad for him. He will also be able do distinguish the objects depending on the stimuli.

   (a) He will be able to generalise and apply some characteristics to an object which is similar but not quite the same as the ones encountered before. This can lead him to an appropriate response.

   (b) He will also be able to discriminate between objects. Based on their appearance he can have a special reaction to them. If the likeness is not to close other reactions might be more appropriate.

Result

If the Bubble is confronted with a similar situation he will try to act according to the behaviour he had learned prior.

4 Simulation Model

In the previous chapter twelve behaviour patterns were introduced. A general description of the behaviour was given to introduce these functions. Based on the descriptions in the last chapter, this one now tries to define what the world and its inhabitants should look and behave like. First the design of the world and the objects in it are of interest. If the world is a very simple one, the behaviour of the creatures in it can be very simple to suffice. But for any sophisticated behaviour to make sense, the world has to contain some complexity. Therefore the world has to provide the means on which the Bubbles can use their mind on. In this chapter the objects of the world, required for a meaningful execution of the previously explained behaviour patterns, are described in Section 4.1. In Section 4.2 the agents abilities to execute the required behaviour are discussed. This includes the psychic functions required by the Bubble as well as actions and perceptions to interact with the world and other Bubbles. The last part of this chapter, Section 4.3, presents the test cases for the use cases described in Section 3.2. An explanation will be given what behaviour is expected in a certain situation.

4.1 World Description

In this section the world of the Bubbles will be described. As mentioned in Section 2.4.4 a simple world has been created before. This world basically consists of a small number of objects. Energy sources are located in the environment and can be used by the Bubbles to regain energy. Obstacles in the environment make it harder or impossible for the Bubbles to reach a region. The other Bubbles are organized in groups, which can be helpful, enemies, or they can fulfil social functions.

Based on the descriptions of the behaviour patterns, some additional objects will be introduced to the world. These will make the world inhabited by the Bubbles a little more complex. This will lead to the necessity for the Bubbles to use certain features of their abilities and help to determine if a certain behaviour emerges.

The term “object” which has been used here has to be clarified. It is used for everything in the Bubble Family Game which is not a Bubble. These objects can be just passive entities, which can be manipulated by the Bubbles and in this way serve a purpose. But this can also be some creature, which is able roam around and take some actions.

World

The world is the environment the Bubbles live in. Its purpose is to provide all the means for the Bubbles to put their abilities to good use. It has to provide challenges and conflicts for the Bubbles. Otherwise the higher mental abilities of the Bubbles would be wasted. Advanced abilities which are not needed for the survival of the Bubbles could even be a disadvantage if they use up resources.

Attributes The world and its attributes can vary. The size of the world can be adjusted to fit to the needs of the test cases. For tests that only involve one or two Bubbles and a handful of objects a small world will suffice. For some settings the world has to be much larger compared to the size of the Bubbles. For example if it is of interest if the Bubbles are building groups or are living on their own. If the Bubbles live in a world significantly larger than they are, it would possibly enforce the building of groups among them. Reasons can be that they need other Bubbles for food gathering or procreation. If they live closely together it is easier for them to get help from others.

Difficult Terrain

Difficult terrain makes it hard for Bubbles to reach a certain region. If the Bubble crosses this terrain, it will cost him more energy than usual. This can mean his movements are slowed down on this terrain, like a swamp. Or that he has to invest more of his energy to get through, like climbing up a hill.

Attributes The purpose of the difficult terrain is to make it harder for the Bubble to cross it. Other than that he has no possibility to interact with it. A stronger constitution might enable him to pass it more quickly. He could also learn to get over this terrain more quickly.

Use Cases A difficult terrain can be used in the decision making use case. It can make the reaching of a goal harder and the Bubble has to invest more, thus causing a conflict in the Bubble.

Different Weather and Temperature

In a large world the weather and temperature can be different in different regions. If every Bubble has a temperature span where he feels fine this can be influenced by the external temperature. This in turn can have an influence on his emotional reactions. If the temperature is comfortable for him, he will be feeling good. If the temperature is to high he might feel uneasy and, as with humans, he might get agitated and more aggressive. If the temperature is too low he might need more energy to maintain his temperature homeostasis. If he has to keep this state up for a longer time it can exhaust him. The presence of wind can cause a Bubble to feel cold.

Attributes This is an environmental factor which can change from place to place. The change happens gradually however. It may also change over time in one place. The change of temperature will happen slowly. A change between sunshine and rain can happen much faster.

Use Cases Different environmental conditions can be used to test the emotional reaction of the Bubbles. A higher temperature than they feel comfortable with, can raise the disposition for aggression. If it is windy or raining the Bubble is likely to seek some shelter. This can influence group finding strategies. The Bubbles are likely to gather in places where they are protected from the wind or the rain.

Obstacles

The other possibility is an obstacle which makes it impossible for the Bubble to pass or even look through, like a thicket or a rock. If the Bubble would run against it or try to pass it, he would get hurt and loose some energy.

Attributes These obstacles are immobile and can not be passed by a Bubble. They are passive but can hurt a Bubble if he runs against them. An obstacle completely blocks the vision or other senses of the Bubble.

Use Cases Obstacles can be used to produce frustration in order to provoke an aggressive reaction. Frustration can be elevated if the reaching of a goal is hindered unexpectedly and shortly before it is reached. An obstacle can block the view of a Bubble who is reaching an object shortly after another.

Portable Energy

Energy is needed by all Bubbles to survive. If a Bubble runs out of energy he will die. Therefore energy is a good which is of universal value for the Bubbles. If they are able to carry some energy around, they will be able to exchange it for other things they might need. This can be other goods or some help it they need it. The amount of energy a Bubble can carry around has to be limited of course. It would not be useful if a Bubble can pick up every energy source it encounters and take it with him.

Attributes As the name already explains these energy sources can be carried around by the Bubbles. Therefore they may have to be able to be parted so only a portion of a larger energy source can be taken away.

Use Cases The portable energy can be used in the reciprocity use case. It can be handed over to another Bubble as a present or as payment for some help in a difficult situation. It can also be used in the specialization use case. Some weaker Bubbles can harvest smaller energy sources which do not provide as much energy. They can be easier to harvest however and produce a more constant output than hunted animals.

Different Nutrients

Different nutrients can be provided, which are all needed by the Bubbles. There can even be a different need among individuals of Bubbles. This can be based on the sex of the Bubbles and different circumstances. These circumstances can be more energy requiring tasks like running or hunting. The nutrients then have to supply the Bubbles with more energy, as is the case with carbohydrates or fat in real life nutrition. Other nutrients can be required for the development of the Bubbles, especially if they are young. These nutrients can be gathered from different sources, each providing a certain amount of some of the nutrients but lacking others. If a Bubble is not getting enough of each nutrient he will suffer from malnutrition.

Attributes Different nutrients are required for different tasks in the Bubble's metabolism. There have to be at least two different nutrients. One is providing the Bubble with energy which will enable him to act and stay alive. The more a Bubble is active the more he will need this energy-rich nutrients. The other one is more like a building material. An adult Bubble only needs a small amount of them to build up or replace tissue. A pregnant mother will need more of it because the unborn child will need it for its development. A developing child after birth will still need more of the building nutrients until he has reached adulthood. The nutrients are not available in all sources. Some are present in one source, and some in others. The building nutrients should be more difficult to acquire than the energy nutrients.

Use Cases The energy nutrient will occur in almost all scenarios. They are needed by the Bubbles to stay alive. The building nutrients are more likely to be omitted by use cases that do not require the Bubbles to exchange something. In some test cases the exchange of nutrients can be used to test the group or family building of Bubbles. Some Bubbles may provide the nutrients required by others and vice versa.

Huntable Animals

The energy sources could be turned into moving objects, which have to be hunted by the Bubbles if they want to gain energy. It would usually take more than one Bubble to get one of them. Getting one alone would be a very lucky incident or require some advanced technique. There are two possible cases for huntable animals. The first one concentrates on the teamwork of the Bubbles. In this case the animal is more difficult to acquire compared to collectable food. But it is much more rewarding by providing more energy. The second concentrates on different nutrients from different food sources. The hunted food can be distinguished from collectable food by the nutrients they provide for a Bubble.

Attributes On a very basic level the energy source could be immobile. It just needs to be approached by one or more Bubbles to make the energy available to them. A little more advanced would be a chance factor if they can access the energy, making it more likely the more Bubbles are working on it. Still more advanced would be a prey which has the ability to move around. Their speed can vary from slower than a Bubble to faster. If a Bubble has caught one, it can serve as a source of energy for the Bubble and can have the attributes of a portable energy source. The hunted animals are providers of large quantities of energy. A still advanced level would be to let them live in groups so the hunting Bubbles have to coordinate their efforts on one target.

Another possibility would be that different food sources with different nutritions are available. The hunted animal provides not so much energy but much more of the building nutritions.

Use Cases Huntable animals can be used in the dynamic group finding scenarios. They can prove if the Bubbles are able to work together in order to gather food. Also specialization in collecting one food source can be tested. Teamwork also relies on the presence of huntable animals to present the common goal. In other scenarios for group finding, the nutrients of the animals are needed by developing children or pregnant mothers.

Collectable Food

Compared to huntable animals, collectable food is easier to get. But one of these sources is much less fruitful than an hunted animal. However they can be a regrowing steady source of energy. In some scenarios they can be a more energy providing than a hunted animal and thus be an alternative food source.

Attributes These food sources are immobile and can easily be collected by one Bubble. If they are collected, they will regrow over time. They contain smaller amounts of energy than a hunted animal. However multiple sources can be in a small area. The other possibility for collectable food would be a variation in the amount of energy the collected food provides. If different nutrients are available the collectable food is still easy to acquire but provides more energy than hunted animals.

Use Cases The different food sources are mostly relevant in group finding or specialisation scenarios. In some scenarios they are distinguishable from huntable animals just in the difficulty of acquiring them. This is the case in specialisation scenarios where different Bubbles in a group specialise on the collection of certain food sources. For group finding based on different nutrition among other factors, the collected food has to provide more energy for the Bubbles than hunted animals.

Predators

Predators are active entities which can move around and take actions on their own. However, compared to a Bubble their behaviour is rather simple. They can be implemented as purely reactive agents or with very simple decision units. Their only purpose is to pose a threat to the Bubbles. They can attack a Bubble if he gets to close to them. There is one reason to include predators and not take other Bubbles as enemies. If the Bubbles are sophisticated enough they can bargain in order not to have to fight each other. With a separate predator this option is excluded a priori. Furthermore the existence of another active species might enforce the wish of the Bubbles to form a group based on their homogeneity.

Attributes The predators can move around on their own. They are able to form a pack. If they encounter a Bubble the are likely to attack him. If he is attacked a Bubble can either fight them or flee. He will not be able to negotiate with them, like he could with other Bubbles. The size, strength and endurance can vary to pose different kinds of threats to the Bubbles.

Use Cases The predators can for example be used in the reciprocity case to be a threat for a Bubble. This Bubble can call another Bubble for help. This help can either be the first favour or the repayment.

Tools

Tools can make some tasks easier for the Bubbles. Therefore they have a certain value to them. They have to be rare to be desirable by the Bubbles, otherwise the would not have as much value. If they are of some value and desired by a Bubble they can be traded among them or serve as gifts. Possible tools would be weapons to be more effective at gaining energy or against hostile Bubbles or predators. Another possibility would be a bag for carrying more energy with them. They could also have clothes which would give them some protection against harm or the weather.

Attributes The tools can be carried around and used by the Bubbles. They have to serve a certain purpose which makes the tools useful and precious for them. But they are only useful if they are used in the right context. Other than that the attributes depend on the tool. They can have an effect on the environment if used, like a weapon, or they could only affect the Bubble in its usefulness, like clothes.

Use Cases Tools can be used in the reciprocity use case. They can be a gift to another Bubble for help or can be traded against some other tool or energy.

Cover

The main purpose of a cover is the protection from the weather. A cave can shield the Bubble from wind or rain. This makes some places more likely as a gathering place for groups of Bubbles than others which do not have this beneficial factor. They can also provide shelter from predators if they hide from them or are easily defendable.

Attributes These shelters are immobile and are large enough for a group of Bubbles to live and store their things in. They should provide protection from wind or rain and lessen the effects or totally eliminate them. They can also provide protection from being seen or otherwise being noticed. This would make Bubbles less likely be victims of predators.

Use Cases Covers are an additional feature for group finding, as they provide a place where they can gather. This can make them also exposed to the effect of closeness which could trigger the development of love between two Bubbles.

Virus

Viruses can be present in an area and a Bubble can probably get infected if he passes through this area. If one Bubble is infected with a virus there is a probability that he will infect other Bubbles, which get in contact with him. A virus can cause a Bubble to become ill. If a Bubble gets infected, his immune system will have to deal with the infection.

Attributes A virus can be present in an area or within a Bubble. The virus has a probability to infect a Bubble if he passes through an infected area. The virus can also be transmitted to another Bubble. If a Bubble is infected and stays in an area for some time, this area will become infected too. The density of the infection depends on how ill the Bubble is. Infected areas will slowly decrease in virus intensity, which decreases the probability of infecting a Bubble. If a Bubble gets ill from the virus, the probability of infecting other Bubbles rises until he begins to recover. A virus can affect only one system of the Bubbles body or weaken the Bubble in general.

Use Cases The probability of viral infections can be determined among the above mentioned factors on the condition of the immune system. If the Bubble is under a lot of stress, his immune system can be weakened. This would make it easier for a virus to infect the Bubble.

Disasters

The purpose of a disaster is to show the Bubble that nature can have an impact on his life and the life of others. These disasters should be a potential threat to the Bubbles. A disaster could for example be an earthquake, a big fire or flood. If the Bubbles experience a disaster some of them will die or get hurt. This experience will cause an emotional distress for the surviving Bubbles.

Attributes A disaster can not be controlled by the Bubbles and they can not foresee its occurrence. A disaster has a certain area of effect. The intensity of the disaster can vary in different spots, influencing chance of survival for the Bubble. If a Bubble is in the sphere of influence of a disaster he will have a certain probability to get hurt or to die.

Use Cases The disasters are used to determine the effect of a negative event. The Bubbles can not foresee and are not able to influence them. The experienced injuries and death of other Bubbles will cause the surviving Bubbles stress.

4.2 Agent Functionality

If the Bubbles should be able to put their mental capacities to use, they have to be in a complex environment, which requires these capacities. The objects which can be added to the environment were described in the previous section. But in order to use them the Bubbles must have some additional abilities, which allow them to interact with these objects.

Attacking

The Bubbles should be able to defend themselves against enemies. The same ability can be used to kill animals in order to gain food. The Bubble has to be very close to the target in order to inflict damage. How much damage is inflicted can vary from Bubble to Bubble and is dependent on their abilities. It also has a chance factor how much damage is inflicted. This makes fights less predictable for the Bubbles.

Prerequisites In order to attack the Bubble must have the physical ability to inflict damage on a specific target. Therefore he first has to sense the target and he has to be able to judge if it is possible to attack the object or opponent from his position. If he is not able to attack from his position, he has to judge where he has to move in order to get the target into his range of action. The reason for the attack determines the psychological prerequisites for the attack. If it is a predator he has to have a survival instinct which triggers the aggressive response. For the fight between two Bubbles they have to have enough aggressive energy build up and determined the other one as the source for their aggressive feelings. For hunting moving animals it is necessary for them to run after them or hunting them coordinated together in a group so it can not escape.

Carrying and Using Objects

Some objects in the world can make the life of the Bubbles easier if they use them. Therefore they have to have the ability to carry the objects with them. Every Bubble has the capacity for only a small number of objects. Some of the objects can be used on the environment, like a weapon on an animal or opponent. Others only have a passive value like a basket for collecting food and carrying more of it. The objects can also be exchanged between the Bubbles and thus making bartering possible. This possibly makes negotiations between them necessary.

Prerequisites The Bubble has to have the physical possibility to carry objects. The bubble has to have a limit how many objects he can carry or in what quantity he can carry them. It also has to be defined what consequences carrying these objects has on his other abilities, for example the weight of the objects. The Bubble can either have a priori knowledge on how to use a certain tool. Or he can find out through try-and-error what an object is good for. This requires a clear cause and effect understanding. He needs to have a clear understanding what a tool does, when he uses it or what result he can expect if he uses it.

Asking for Favours

If a Bubble asks for a favour, he wants another Bubble to do something for him. Examples for favours are help against enemies or gathering food. The favour in question can be accepted or rejected by the other Bubble. As long as the other Bubble is not altruistically motivated he wants to get something out of it. This possibly might make negotiations between them necessary.

Prerequisites In order for a Bubble to ask for a favour he has to have a clear understanding what he wants to achieve. Further he has to understand that he can not or will not do it himself or alone. He might have to be able to determine if the other Bubble can help him achieve his goal. He has to have an understanding not only what he can do, but also what another Bubble can do. He needs to know the difference between his and the other Bubbles abilities and what can result if they join their forces. He also has to have the ability to judge the other Bubbles intentions in order to foresee if the other one might want to help him achieve his goals. Physically he has to have the ability to tell the other Bubble what he wants to achieve and how he wants him to do. The other Bubble has to have the ability to receive and understand the request. He has to judge if he wants and is able to comply to the request and confirm or decline his request.

Giving and Receiving Instructions

Instructions are given when someone higher up in a hierarchy decides what a group should do. If the goals of a group are not predefined, the group needs a hierarchy as a basis for joint actions. A democratic decision among the group members would be possible but requires much more coordination. If a hierarchy with at least two layers, meaning a leader on top of the group, is established, he is responsible for determining the goals and actions of the group. Usually it has social consequences if one member of the group is not acting according to the instructions given to him.

Prerequisites Instructions between individuals require some form of hierarchy in a group or among individuals. The included individuals of the hierarchy have to be aware of their position and who is giving and who is receiving instructions. Giving instructions requires that one individual has the ability to decide what goal should be aspired. He has to be able not only to decide for himself what to do but also include other individuals as well in his planing. Some tasks at hand might not be manageable by sheer numbers. They can be more complex and require different group members to execute different tasks. The leader has to be able to coordinate the actions and give instructions to individuals which are different than those of others. The leader has to be able to at least communicate what the goal is he wants the subordinate to achieve. More advanced would be the information about how it should be done. The subordinate has to be able to understand what the goal is or what the superior wants him to do.

Display of Affection

The display of affection results out of love and could be an activity like kissing. This can serve two purposes. First it can show the other Bubble the affection the first one has towards him. This may be able to change the feelings of the other Bubble towards the first one. Second it can serve as a means for getting a drive satisfaction. If both Bubbles are showing their affection for each other, it will be satisfactory for both of them.

Prerequisites The Bubbles have to have the physical ability to show each other their affection. It has to have a physical component for both of them in order to satisfy the drives which are the sources for their needs. This physical component has to be sensed by the other Bubble to take effect. They have to have the ability to love another Bubble and to get satisfaction out of the affectionate interaction with each other.

Intimidation

Intimidation is usually a process which precedes physical aggression. It can also be used to frighten someone with the possibility of a physical attack in order to reach a goal. It is used to show an opponent that the individual is willing and able to attack and hurt him. In the real world this usually includes signs like showing the teeth, accompanied by a threatening sound and making oneself larger. Intimidation can be used in two ways. It can be used in a defensive way. The individual can try to scare of an attacker by trying to convince him that he is not an easy target. Or in an offensive way he can try to scare another individual to achieve something.

Prerequisites The Bubble has to have the physical ability to show a disposition to behave aggressively. It has to be unmistakeably clear to the second Bubble that the first one is willing to use aggression. Therefore he has to be able to perceive the aggressive stance of the first Bubble. If the intimidation is used defensively it is possibly an inborn mechanism to ward of enemies. If it is used offensively the aggressor has to be the insight that his actions might frighten the other one enough, that he will give in to the threat.

Homeostasis

Every organic system within a living being has a small range around a set point within which it will work properly. The values regulated by these organic systems can be the blood heat or heart rate. The more the actual value deviates from the set point the more the organic system tends to fail to work properly. The individual will start to feel uneasy or ill. If the values deviate to much from the set point it will result in the death of the individual. The task of the mind is to try and keep the homeostasis of the body as close to the set points as possible. This can happen through ingesting something or by changing to another, more comfortable location.

Prerequisites The body of the Bubble has to consist of some systems which are necessary for him to keep alive. These systems have to have a set point which indicates an optimal performance. This set point can vary within small limits from individual to individual. The more the actual value now deviates from this set point, the more the affected systems start to fail or cause the Bubble to behave out of the ordinary. In some cases the Bubble will be able to determine what causes the deviation. This will most likely happen for external causes. In this cases he needs the ability to assign the external causes to the effect of his indisposition. In other cases he will not be able to determine directly what system is not working correctly. He will only be able to perceive some symptoms. These will in most cases be internal causes. The mind of the Bubble now needs the ability to determine what he could do to relieve his distress.

Psychosomatic Illnesses

Psychosomatic illnesses are maladies which do not (seem to) have an organic cause. They are caused if the individual is experiencing a continuous emotional distress or chronic stress. If the distress of the Bubble continues for too long one or more systems of his body will leave the state of homeostasis. This does not have an external cause, but is possibly due to the continuous low activation of the system without relief. If the mind is worrying or under a lot of stress it puts the system slowly but constantly out of the homeostasis. After a while the system will start to malfunction. If the mental cause for the stress is relieved the symptoms will slowly start to fade.

Prerequisites This functionality is based on the homeostasis of the organic systems of a Bubble and its prerequisites. The unconscious mental abilities of a Bubble have to be able to affect the workings of the organic systems of the body. This will happen through activating the system over a long time period. As long as no illness is noticed by the Bubble, he will not be able to perceive the negative influence of the mind on the system or that it is not working at its set point.

Illnesses

Illnesses force the homeostasis of one or more systems of a Bubble out of balance. If this system fails to function properly the Bubble will have to suffer from the effects of the system working with reduced effect or not at all. It will usually result in a general weakness. If the system returns to homeostasis the condition of the Bubble will be restored again. Causes for illnesses can be a virus, malnutrition or simply the fact that a Bubble gets old.

Prerequisites The Bubbles physiology must consist of one or more systems which serve a certain purpose for the life and health of the Bubble. These systems have to have a value where they are in homeostasis. In case one of these systems are not in homeostasis the efficiency of the Bubble will be reduced. If the Bubble fetches a virus some or all of the systems are brought out of homeostasis. The Bubble must have an immune system which is able to fight these viruses. In case of malnutrition, the required nutrients are not provided, which hinders the system depending on it to work properly. In case of an ageing process the systems are decreasing their efficiency progressively.

Immune system

If viruses are present in the world, the Bubbles must have a way to deal with them if they get infected. The condition of the immune system determines if an infection with a virus leads to an illness of the Bubble. The higher the virus density and the worse the condition of the immune system is the higher the probability of an illness. As every system in the Bubbles body, the efficiency of the immune system can become gradually restricted. One cause can be stress which makes the Bubble more susceptible for illnesses. With progressing age the Bubble's immune system will also become increasingly inefficient.

Prerequisites For an immune system to be useful there have to be viruses present in the world. Also factors which influence the immune system like stress are necessary.

Malnutrition

Malnutrition refers to the fact that a body is not supplied by some nutrients which are necessary for it to keep working properly. If the Bubble is not getting some of the nutrients, some systems which are dependent on them will fail to work properly or at all. This will cause a general weakening of the Bubble and the Bubble will become ill. If the body is supplied with the required nutrients it will slowly return to normal again. If a female Bubble is pregnant the effects will also have an impact on the child. The effects on the unborn child can be physical or mental and might influence the future development and abilities.

Prerequisites There have to be different kinds of nutrients in the world. These nutrients should be present in different kinds of food. These have to be required by the systems in the Bubble's body. Malnutrition brings the homeostasis of the affected system out of balance, which can have an effect on the Bubbles abilities.

General Procreation

On a simple basis two Bubbles meet and engage in a procreational act. Instantly a new Bubble is created which has the same abilities his parents have. This simple form of procreation does not include different genders or child development. The new Bubble is created as an adult with all the abilities needed to survive in this world. This functionality can be further elaborated by adding genders, ageing or evolution.

Prerequisites Two Bubbles must be able to engage in a procreational act. The Bubbles should have an inborn drive to procreate occasionally. But the rate at which the Bubbles procreate should be limited. Otherwise the Bubbles could concentrate too much on it. There would be the risk of overpopulating the world if the Bubbles engage in procreation to much in order to enjoy pleasure. Some form of initial knowledge about the world has to be passed on to the new Bubble. A basic form would be a generic predefined set of knowledge. Additionally some individual information from the parents can be passed on. This can happen similarly to genetic algorithms.

Gender Based Procreation

Different genders are an addition to the functionality of procreation, making it a little more complex. There are two different genders which will both be needed for procreation. The procreational act can be the same as before. The only difference is that the child also has to have a defined gender. The introduction of genders may have unforeseen influences on the social life of the Bubbles.

Prerequisites General procreation is a prerequisite for this case. Additionally there have to be two different genders present among the Bubbles and they have to be aware of what gender they have themselves. They also have to be able to determine what gender other Bubbles have. An inborn knowledge about with which other Bubbles they can procreate is needed.

Childhood

Childhood refers to the first time after a Bubbles birth. The new Bubble is equipped with only a small set of basic emotions and reactions. He will have to learn everything else from his parents and other Bubbles around him. Alternatively he can learn from observing the environment and learning through imitation. In this first time he will depend on his parents to survive. He will need to be protected by them and he depends in his nutrition on the food he is provided by his parents. Since he has to develop physically, he has to receive the right nutrition which not only provides him with energy but also with nutrients needed for his development.

Prerequisites A newborn Bubble will have a small set of knowledge. This means basic reactions the child needs to survive. These reactions are for example eating if the child is presented with food. However the child will not know and not be able to acquire it himself just then. He also needs emotions to motivate him and give his parents a feedback on its well being. This means some expression of the emotions it feels, like smiling or crying. The helplessness of the child requires the parents to have a drive which urges them to care for the child. They have to know the needs of the child and interpret its expressions right. If the development of the child

depends on the right nutrition, it has to be provided by the environment. Some sources of food might provide more of one nutrient than others.

Childcare and Education

The female Bubbles act as the ones giving birth to the child Bubbles. During pregnancy and the first time after birth, the female Bubbles will not be able to provide enough food for themselves and the child all the time. The male Bubble will have to provide the food in these cases. The female Bubbles will have the task to protect the children while the male Bubbles are away. They will also be the source of education since they are present for the children most of the time. The child will observe the parents and learn from their behaviour.

Prerequisites The prerequisites for gender based procreation is also applicable here. Additionally the Bubbles not only need an interest in keeping the child alive but also preparing it for a survival on his own. The child has to be able to learn from observing what other Bubbles are doing and what effect it has.

Learning from Observing Others

If a Bubble is born as an infant he will have to learn from others what he needs to survive. He will have to observe others and then try to imitate what other Bubbles do and what effect it has.

Prerequisites The Bubble has to have the ability to observe a chain of action and determine cause and effect. They also need the ability to replay the actions in their thoughts. Then they need to project this actions onto themselves in order to realise that they are able repeat this action.

Ageing

Ageing means that a Bubble has a life span where his abilities are fully available. This span can maybe prolonged through a healthy lifestyle, but not reversed or stopped. If he gets older and leaves this predefined range of age, his abilities will progressively become worse. The affected abilities can include physical as well as mental abilities, like dexterity or the working of memory. The progressing age increases the probability that one of the systems will fail to work. If one does it depends on the importance of the system how much time it takes until the Bubble dies.

Prerequisites The Bubbles have to have a predefined range of age where their systems work properly. The working of these systems should be able to become gradually worse with progressing age. The systems should have a probability which indicates the likeliness of a failure of the system. If the system is critical for the Bubbles survival it will cause his death.

Practising Abilities

The Bubbles can have various abilities which determine how efficient they can do something or complete a task. This can include inborn functions like running. If a Bubble runs a lot he will get more stamina and will be able to run faster. It can also influence how well he can manufacture something. If he can build tools, his practice can influence the endurance of the object, how efficient the tool is and how quickly he can manufacture it. It can also mean that a Bubble who fights against enemies a lot, will get more efficient and his probability of winning a fight increases. Getting better at something needs practice. This requires that a Bubble has to do it over and over again which can be time consuming. In the end it can lead to a specialization of the Bubbles in a group if they realize that they are more efficient if a Bubble does the things he has practice in.

Prerequisites Some of the abilities, like running, can have a range of how well a Bubble can execute them. If a Bubble practices them a lot the limits will slowly be set higher. The better the Bubble gets the harder it will become for him to get even better. It will take more practice to get better. Other actions can have a probability of success. If a Bubble fights against a predator, a probability can define if the Bubble is able to hit the target he aims for. With practice the probability will increase.

Emotional Expression

In order for the Bubbles to socially interact it is necessary to express their emotions. The others have to be able to know what a Bubble feels. For example if a Bubble is angry and shows it, the others will know that they should not provoke him if they want to avoid a fight. For young Bubbles which are not able to speak yet, it becomes important to express their feelings to their parents. In this way they can tell them that they need something or they are happy. Therefore it is necessary that some of these expressions are inborn.

Prerequisites The Bubbles need to be equipped with emotions which are adequately representing what they feel. They have to have a physical way to express what they are feeling. This can happen through mimic expressions or gestures. The other Bubbles have to have the ability to perceive these expressions, interpret them correctly and act on them. This means they need some kind of empathy to understand what another Bubble feels and what he needs.

Evolution

It is questionable if all of the behaviour of the Bubbles can be implemented. Possibly some complex forms of behaviour, which are specific for the artificial world, can not be added from outside but only from within. This can happen only through a trial-and-error process. Some form of genetic storage of basic behaviour could enable them to pass useful behaviour on to the next generation. If some behaviour is not fit for the world, the respective Bubble will not have a chance to procreate and will die without any successors. New behaviour can be created by combination of the parents genes and a mutational process on the information when a new Bubble is created. A fitness function in the Bubbles could determines if a new Bubble is selected by another Bubble for procreation.

Prerequisites The Bubbles need some kind of virtual genes, which can store some basic form of behaviour, their abilities what they look like. Ideally this mechanism is extremely flexible and can be changed to something completely different. In appearance as well as in functionality. This requires some form of procreation, where two Bubbles are mixing their genes and thus creating a new Bubble. Gender based procreation would be preferable. One gender tries to spread its genes as wide as possible thus enforcing the procreation as much as possible. The investment in the procreational process has to be relatively low. The other gender has to invest more and thus tries to select their partners carefully. This additional investment would happen through additional nutritional need and restricted mobility, making the Bubble more vulnerable. Both genders need some sort of fitness function, which determines if a Bubble from the other gender can be assumed desirable for procreation. The wish for procreation has to be present in both. This can be enforced through pleasure from the act. For the less investing gender it can be easier to gain pleasure and harder, but still possible, for the more investing.

Different Physical Appearances

Appearance does not only include the looks but also other perceptions like sound or smell. Different physical appearance is meant for the Bubbles as well as the surrounding objects. For the Bubbles it can serve as a way to distinguish one Bubble from others. This can lead to physical similarities between some Bubble and differences between others. This can be the basis for a physically based similarity as the cause of love. If the objects have a varying look the Bubbles abilities for generalisation and discrimination can be tested. Do the Bubbles recognise a predator if it looks slightly different? Or do they mistake a huntable animal for a predator based on minor similarities?

Prerequisites The looks, sound or smell should be able to be varied on a scale. This could be the colour or the size of an animal which can either be hunted or be a predator. It could also mean the sound an animal makes. These attributes should be qualified to give the Bubbles a hint if the object is good or bad for them. Or if they do not know an object yet it could even give them a clue what to do with it. Maybe an object, which smells good could be eaten. It also means that similar objects have similar characteristics. The sound of some predators should not vary to much if the Bubbles should be able to recognise them as such.

4.3 Test Cases

The test cases described here have been extracted from the use cases in Section 3.2. Their goal is to test the behaviour of the Bubbles and if the specified behaviour emerges. Since the aim is to test the emergent behaviour of the Bubbles, the test cases will not look into the Bubbles and the values they contain. The tests applied are pure black box test cases in their principal nature. As with real behaviour of humans, the only judge if the behaviour actually occurs is a human spectator. The only problem is, as with all behaviour and this will possibly be the case here as well, that it is not entirely predictable. Only a few guidelines for what is expected to happen can be given. Nevertheless the test cases try to cover the most likely behaviour which can result from a scenario. Also some implications what the result means for the use case will be explained.

The behaviour of the Bubbles does not have to show immediately. Sometimes it can take a little while until the behaviour is shown by the Bubble. Or it can take some time until the Bubble

has learned that behaviour. In some test cases, it might be necessary to watch the simulation for some time to make sure the behaviour is unlikely to emerge.

The test cases are usually based on the causes which trigger the behaviour in question. As it is in the real world, there is no guarantee that an individual will show a certain behaviour in a certain situation. One individual might act in this way, the second in another. It is hard, if not impossible, to foresee how an individual will actually react in a certain situation. A cause for a certain reaction in one individual might cause an entirely different reaction in another. It might work the same way in a simulation. Which reaction will be invoked is impossible to foresee. Partly of the reasons mentioned before, partly because there are little to no empirical values, how Bubbles react in this specific situation. Therefore in the beginning of the tests it might be considered a success if a Bubble reacts in one of the specified test cases as he is expected to be.

Love

Agents Two Bubbles are needed who are planed to fall in love. "Promiscuity" might occur if more Bubbles are present, which could be considered as group finding.

Objects Objects are optional for these test cases. A task can be given to two Bubbles in order to let them work together, which can increase the feelings.

Test Cases The test cases are sorted by their trigger why the Bubbles fall in love with each other. Maybe one of the cases might not be enough to develop a close bounding between two Bubbles. More than one factor might help in developing a feeling of affection for another Bubble. Furthermore it is quite possible that these cases are not separable at all. Closeness might lead to affection, which is then reciprocated enforcing the feelings. The importance of the excitement for the attribution of love to the other Bubble is to be tested.

No.1: Effect of Closeness Two Bubbles are spending some time in the same area. They should still sense the other one most of the time, even if it is interrupted for a short timespan. This should make them accustomed to each other. Then a physical or emotional excitement will be introduced which has the intention that it should be attributed to the other Bubble. If this works out fine for both of them they will seek the vicinity of the other one again. In the end, they both will show their affection for each other.
The two Bubbles are spending some time in a place. This can be enforced if they have a task on which they can work together. It should be physically challenging, like climbing up a hill in order to get something. Another possibility would be a threat like an attack from an enemy. It does not have to be a hard fight, the purpose is just to make them excited. After some time they will try to stay together and show signs of affection.

No.2: Similarity The Bubbles need to have something in common, like values, preferences or appearance. They also have to have the need to make sure their values and opinions are shared by others. In order to determine if another Bubble has the same values a situation has to be presented to them, where they can show the same behaviour. If others have the same values, it makes the Bubbles feel good. This increases the chance that the Bubble will seek the company of the other ones sharing his views.
The tests for similarity can be based on the physical appearance of the Bubbles. Therefore

some Bubbles have to have a different look. This can be either based on their own bodily appearance or on some clothing they are wearing. It can also be based on some preferences, like for similar food or a certain pattern of reaction in a certain situation. If two Bubbles flee from a threat, they might feel affirmed in their reaction and start to like the other Bubble.

No.3: Reciprocal Affection One of the Bubbles has grown fond of the other one. The second Bubble is not interested in the first one but is not disaffected. The first is now showing signs of affection towards the second one. After a short while the second Bubble should start to return the displays of affection.
One Bubble, who's actions can be predefined, is displaying signs of affection for the other one. It may take some time and more than one try, but eventually the other Bubble will reciprocate the affection for the first Bubble.

No.4: All of the Above It is of course questionable if one of the test cases above will result in loving feelings. A separate test case, which combines the factors of above, is created. This includes the closeness of two Bubbles, similar reactions or appearances and the display of affection from one Bubble to the other. This will soon result in the display of affection from the other Bubble.
In this test case one Bubble will be scripted. The scenario will start as test case No.1 with the Bubbles spending some time and getting a task which excites them. The Bubbles get the chance to show a similar reaction to the task. After spending further time together the scripted Bubble will start to show signs of affection. The second Bubble will soon start to reciprocate them.

Aggression

Agents One Bubble is showing the aggressive behaviour. Another Bubble can be the source of pain, frustration or provocation.

Objects A desired object can be used as the source of frustration. It can be placed in the environment and spotted by the Bubble. Shortly before he reaches it, it will suddenly be taken away by another Bubble.

Test Cases There are four possible test case classes. They are sorted by the trigger for the aggressive behaviour. One class, provocation, can in some cases implicitly be included in the other three. Aggression as a response of perceived aggression is always possible.

No.1: Pain If a Bubble is attacked by another Bubble, this can cause aggression through pain. The Bubble now has two options. He can attack if he thinks he can win or is angry enough. If there is a fight it can continue until one of them dies. Or he can flee from the other Bubble in order not to get hurt anymore. Either if he is afraid or if he does not think he can win the fight. If he can not flee the Bubble will most certainly attack to save himself.
A possible scenario would be that one Bubble is suddenly attacked by another Bubble without warning. This can happen either in the open where he is able to flee. Or the Bubble can be trapped without much chance of escaping the attacker in order to force him to attack.

No.2: Unease If a Bubble is not feeling well due to internal or external reasons he is likely to behave aggressively. This can be an intimidating behaviour if he interacts with other Bubbles or he can simply attack to "let of steam". The other Bubble can flee from the first one. He can also show intimidating behaviour or he can respond to the threat with an attack. If the other Bubble is also suffering from the situation he is likely to attack. A resulting fight can go to the death of one of the Bubbles, which is unlikely to change the situation for the other one to the better. There is always the possibility for one of the Bubbles to flee where the relief of the unease is dependent on the cause.
Possible scenarios would be a high temperature in the environment. The place where the Bubble resides could be overcrowded. A result of that or a separate scenario could be a lack of nutrition and resulting hunger.

No.3: Frustration If a Bubble gets frustrated he can try to rely on aggression to solve his problem. If another Bubble is the source of aggression he can show intimidating behaviour until the other one flees or also reacts in an aggressive way. An aggressive response can lead to a fight which can end by the flight or the death of one of the Bubble.
A possible scenario would be if one Bubble is hungry and senses an energy source. The view to another Bubble, also approaching the energy source, is blocked by an obstacle. The second Bubble arrives at the energy source shortly before he does and takes it away. This unexpected negative disappointment shortly before the goal should increase the frustration of the Bubble. Now he can demand the energy from the other Bubble or directly attack him to get it.

No.4: Provocation If a Bubble is confronted with aggressive behaviour, either through intimidation or through an attack, he is likely to respond in an aggressive way. This can lead to an escalation of the situation and result in a fight. It is also possible that one of the Bubble becomes afraid of the other or rationally tries to avoid a fight and flees. If their communication skills are sophisticated enough the second Bubble could also try to calm the first one down. Also it has to be mentioned that the possibility of provocation through aggressive behaviour is possibly implicitly included in all the other cases.

Dynamic Group Finding

Agents For these test cases obviously a collection of Bubbles is needed to observe their behaviour as a whole. The groups should not be bigger than about five individuals. Larger groups hardly provide any additional insight into the workings of the group.

Objects For the threat scenarios predators in varying strength and numbers are needed. They pose a threat to the Bubbles which they can only master together. Huntable animals are needed, if the ability of the Bubbles to work together for their nutrition should be tested. If the Bubbles should be able to share goods they have to be able to exchange things of value to them. This could be some energy or tools which they can use. The gender dependent nutrition requires that multiple nutrients are available in different sources.

Test Cases For dynamic group finding the differentiation between the test cases is based on the tasks a collection of Bubbles is given. The purpose is to look how they react to each of these

threats. When it comes to facing a threat or they are given a task they should all work together and help each other. It also includes sharing resources among each other.

No.1: Big Threat The Bubbles are living in a space closely together. Then they are presented with a threat they can only master together. An additional encouragement can be if this threat may take away something they need for living.
A scenario could be that the Bubbles are living in an area where they have enough supply for their living. Outside of this area they will starve soon or it would be very hard for them to survive. This provides them with a reason to fight for their habitat. Then a large predator is introduced which wants to occupy the area. The Bubbles are not able to beat the predator one by one. They have to face him as a group to defeat him.

No.2: Multiple Smaller Threats This test case is similar to No.1. The initial setting is the same. The difference is that not one big threat is introduced but some smaller threats. However they pose a similar threat like the large one. This will show if the Bubbles perceive a number of small threats as a threat, they can not handle alone.
The scenario could be the same like before. But instead of the large predator some smaller ones are introduced. A Bubble could be able to defend himself against one of them, but if he is attacked by a group he will not be able to survive. However a group of Bubbles will be able to defend themselves against the predators.

No.3: Hunting Together The Bubbles could be dependent on hunting for their nutrition. If they work together it will be much easier for them to be successful. If the hunted animal is able to escape a single Bubble, the hunt will cost each individual less energy if they work together.
A basic setting could be some energy sources which can only be opened by more than one Bubble. They would need to work on it together in order to gain energy from it. A more advanced setting would be that the only energy sources could be some huntable animals which are moving around and can try to escape the Bubbles.

No.4: Sharing Goods Members of a group can share and exchange goods. If one member of the group has a tool which is needed by another Bubble it can be shared among them. If one of the Bubbles was luckier in collecting energy, he can share it with another Bubble which was less successful. Also the creation of tools and the exchange for other things is more easy in a group. One Bubble could make tools while others concentrate on collecting energy. If there are other individuals around, the goods can be traded easierly. This would require the Bubbles to have the ability of reciprocity as described in Section 3.2.10. If some of the shared goods have to be crafted, it would require that the Bubbles are able to specialize on certain tasks as described in Section 3.2.5.

No.5: Sexual Procreation and Child Care The need for procreation has to be inborn for the Bubbles to ensure that they form some kind of a family. Also the need for childcare has to be predefined if their offspring should stay alive. This requires that the children are not able to survive on their own during the first time after birth. This keeps them together to ensure the safety of the children. The task of sexual procreation in a large world is made easier if they live in a group and it is possible to conceive a child at any time. It is easier to raise a child in a family or group if some team members look after the vulnerable children and others collect food.
A setting could be an environment where the food has to be hunted by the group members.

A pack of predators is roaming the area and if the children of the group are left unguarded they might become the prey of the pack. If some of the group members stay with them they can fend of the predators together while the others hunt the food. This test case is an extension of No.3.

No.6: Gender Dependent Nutrition This test case can be seen as an extension of the previous one or to be used on its own. As mentioned above the Bubbles have to have different genders. Both are needed for procreation if they want a child. The need for procreation has to be inborn to ensure the Bubbles will not die out. Also their drive to care for their children has to be inborn to ensure the survival of their children after birth. The different genders of the Bubbles have to have different nutritional needs. This applies especially to the women during pregnancy. They will need more nutrients which are necessary for the development of the child. This nutrients can be gathered from huntable animals. Female Bubbles, and especially pregnant female Bubbles, are not able to hunt them themselves. They have to rely on the male Bubbles to provide them with the food they need. The female Bubbles are however able to gather other nutrients which the male Bubbles need to hunt animals. The female Bubbles can do this even during pregnancy. The collection of this food is easy, but can be time consuming. The male Bubbles could collect this food themselves. But this would leave the females and the children without their required nutrition. If the females are not supplied with the required nutritions they can become ill and their children might be weak or disabled. Therefore, the interest of both genders in the survival of their children is needed to keep them together. This ensures the well-being of all of them the parents as well as their children.

Hierarchy

Agents Multiple agents are needed to determine if a hierarchy has been established in a group. Two might suffice but some more can be useful.

Objects Objects are needed in this test cases to create a shortage. The objects have to be needed or wanted by the Bubbles. Energy sources with only a small amount of energy can be used to create a shortage of energy. This will threaten the survival of the group and its individuals. If the Bubbles are able to sexually procreate, this can also be used to create a shortage of individuals which have a higher investment in the procreation.

Test Cases The test cases are sorted by the behaviour when the Bubbles realize the shortage of the supply. The kind of resources which are lacking is of minor importance. They should be replaceable as long as the Bubbles need it in some way. In the following descriptions a shortage of energy will be considered.

No.1: Predefined Hierarchy In the initial situation the group of Bubbles has enough resources. Over time the remaining resources become less. The Bubbles, which are higher up in the hierarchy, have still access to the remaining resources. The Bubbles which are lower will get less or none of them. This might even lead to severe consequences for the hierarchically lower Bubbles.
The Bubbles are confronted with a shortage of energy. The remaining energy will last only

for some of the Bubbles but not all. The Bubbles which are higher up in the hierarchy will still have access to the energy while the other Bubbles will have to hunger and eventually starve.

No.2: Intimidation In the initial situation the group of Bubbles has enough resources. Over time the remaining resources become less. The Bubbles will eventually realise that the resources will not suffice for all of them. They will start to establish a hierarchy by determining who is superior. This will be done by intimidating other Bubbles. The Bubbles will have to rely on their perceptions who is the superior. They will not attack each other physically but only threaten each other. The ones who win will get access to the resources.

No.3: Fighting In the initial situation the group of Bubbles has enough resources. Over time the remaining resources become less. The Bubbles will eventually realise that the resources will not suffice for all of them. They will start to establish a hierarchy by determining who is superior. This will be done by fighting each other. In this case both of them will get hurt or one of them might even die. The fight will determine which of two Bubbles gets access to the resource. But the wining Bubble will still be weakened from the fight. This will result in a lower probability to survive than if they would have established a hierarchy.

Specialization

Agents A group of agents is needed to determine if a specialization among the members occur. The group has to consist of at least two members.

Objects Various kinds of energy sources which have a different difficulty to acquire can be present. They can be gathered by different Bubbles with different physical abilities.

Test Cases As indicated by the use cases there are two primary test cases. The first one should determine if a leader is present in a group. The second should determine if some of the Bubbles prefer some kind of work while other Bubbles prefer others.

No.1: Following a Leader A group of Bubbles which has a leader is staying at a certain place. Then the group is encouraged to move to another place. The group members will wait until the leader starts to leave the place. As soon as he does, the other members of the group will follow.
The group which is staying in one place can be confronted with a change of situation. This can be something that effects the whole group or just the leader. Examples would be a rising temperature which is getting unpleasant or some predators in the area which are too strong for the group. The group will stay as long as the leader does. If he is starting to leave, the group will follow him wherever he goes.

No.2: Imitation of a Leader A normal member of the group can be given a special ability. If he uses it the others will only slowly or not at all imitate his behaviour. If the leader is given the ability the members of the group will much more readily watch him and try to learn the ability. Soon afterwards the group will show the same behaviour which was shown by the leader.
The leader of the group could have some knowledge about how to solve a problem. This

could be the use of a tool for gathering food for example. If the other Bubbles see the success of his behaviour, they will most likely adopt it.

No.3: Division of Labour A group of Bubbles consists of some individuals which have different abilities. Over time they should realise that some individuals are better at some tasks than others. This should lead to a division of labour, where the individuals do the tasks which they are good at. After the work is done, the Bubbles can exchange the products.
Some Bubbles can be stronger and are better suited for hunting animals, which requires strength. This supply can be rich in energy but the opportunity is presented only rarely. Other Bubbles which are weaker can collect food, which is not as rich in energy but provides a steady supply. In this way everyone can provide energy for the group which can be exchanged among the members. The specialization on one food supply does not necessarily require a group. The exchange in times of need however does require other Bubbles who can be sure that they will get something back in return if they need it.
Another possibility would be the making of tools. Some Bubbles could specialize in crafting tools or other things which can be exchanged against other tools or energy. This would require a group of Bubbles where one Bubble who specializes in a certain task can be sure to get compensated for his efforts. If a Bubble would produce goods exceeding his needs it would be a waste of energy. This test case is in interaction with the test case No.4 of Dynamic Group Finding.

Adequate Emotional Reaction

Agents One agent is tested for his emotional feelings. Another agent can be the source of the feelings either by his actions, like provoking the first one or by him helping the first one.

Objects An opponent like a predator or another threat from the environment is needed to invoke feelings of fear.

Test Cases The conditions and tests for test case No.2 are described in the respective section. Test cases No.3 and No.4 can use the existence of love as the source of joy or sadness.

No.1: Fear The Bubble is confronted with a potentially dangerous situation. He should most likely try to flee from the situation. If the threat is an opponent, he can try to hide from him if some cover is available. If neither fleeing nor hiding is possible and the threat is an opponent the Bubble will attack. This will lead to aggression if fear alone is not sufficient to deal with the situation. Every other emotional reaction like joy or sadness would have serious consequences.
The Bubble can be confronted with a large enemy. He should be afraid of it and try to avoid a confrontation. If that is not possible he will attack the opponent.

No.2: Aggression For detailed information on aggression see the according test cases in Section 4.3.

No.3: Joy A Bubble is presented with an unexpected positive event. This will lead him to feel joy and treat the other Bubble, who is responsible for these emotions, friendly. This can even enforce the bonds between the two Bubbles if they associate positive feelings with each

other. If the Bubble responds with fear or sadness, he will not be able to gain a benefit out of the positive event. If he responds with anger and aggression to another Bubble, who is being nice to him, the other one will avoid him in the future.
There are some possibilities for a Bubble to show joy. He could either receive a gift, he could meet again with a loved Bubble or another Bubble could come to his aid in a dangerous situation. This will make him joyous and result in positive feelings toward the other Bubble.

No.4: Sadness If the Bubble loses an object or other Bubble which meant something to him he will most likely respond with sadness. This can be a loved Bubble or an object which was useful or had a personal meaning to him.

Stress

Agents One Bubble is needed for which his stress reactions are examined. Other Bubbles and their fates can be the cause of stress for the Bubble. Especially in life changing events the loss of another loved Bubble can be the cause for stress.

Objects A perpetual threat like predators, which linger in the vicinity of the Bubble's home, can cause chronic stress. For everyday problems, objects the Bubble needs can cause stress if he loses them or can not acquire them if needed. This can include energy sources or tools for example. Traumatic events can be caused by the environment like an earthquake. If it injures or kills some of the Bubbles, it will cause the remaining Bubbles stress.

Test Cases The test cases are sorted by the cause of stress for the Bubble. Some of these test cases can depend on the effects of other use cases, like a loved Bubble. Also a chronic stressor can cause similar effects like the test case of aggression through unease.

No.1: Life Changing Events A Bubble experiences an event which will change the life which he has lead so far. This event can be either positive or negative. The main point is a big change, which will force the Bubble to adapt his behaviour and what he was used to. This test case is difficult since it requires a long simulation run to make a Bubble accustomed to a situation.
A negative life changing event could be the loss of a loved Bubble he spent a lot of time with. They have to get accustomed beforehand and do things together. Then the other Bubble is taken away, possibly by death. As a result the health of the remaining Bubble will suffer. Possibly his motivation too, which maybe has to be ascribed to mourning.

No.2: Traumatic Event The Bubble can be the witness of a traumatic event. This can be a catastrophe which will cost some Bubbles their lives. The remaining Bubble stays unharmed or only lightly injured. But he has to watch the others get severely hurt or die. According to the theory this may cause him to reduce his emotional reactions to situations and result in fewer contacts to other Bubbles. He will be alarmed by similar situations or objects, which he perceived closely related to the catastrophe.

No.3: Chronic Stressors The Bubble can be perpetually exposed to a threat or an unpleasant situation. The constant stress level will have a negative influence on his health or his behaviour. This will cause him to get either depressed or aggressive.

The Bubble is living in a permanent stressful situation. This can be some predators, which are lingering in the vicinity. This can also be an environmental cause, like a high temperature. Depending on the feeling of the Bubble if he can do something about it, he can respond aggressively if he thinks he can change his situation. Or he will become depressed if he resigns himself to his fate. In either case, if the stress goes on for too long, he will likely get some psychosomatic illnesses.

No.4: Everyday Problems One single small problem is not going to cause much stress in a Bubble. What makes everyday problems an issue is that they occur throughout the day in larger numbers. If each little problem adds a little amount of stress, which on its own is harmless, it can become a problem if it adds up. Some small problems, which cause only a barely noticeable amount of stress, can add up if they happen within a short time. This can cause the Bubble to feel stressed.
Examples for stressors for the Bubbles can be not finding any energy, loosing a tool, deception by another Bubble, an uncomfortable environment and many others. If the Bubble is experiencing some of them in a short time he will feel stressed. This will lead to reduced corporal and mental health like heart failures or depression.

Ability to Work in a Team

Agents A group of agents is needed to work in a team. For some of the scenarios one of the agents exploits the effort of the others. Two Bubbles would suffice but a group of four or five Bubbles is better.

Objects The easiest object for these scenarios would be an energy source for which the Bubbles have to work together. It needs to be accessible only through teamwork.

Test Cases The first test case is testing if all members of the group are working together. The alternative if the Bubbles are all pursuing easier but not so rewarding goals alone is tested in the second test case. The last three test cases are concerned with how the group shares the reward among the members.

No.1: Working Together The Bubbles have the choice to pursue a goal together or to pursue a goal each of them for himself. In the first case the result should be more rewarding for each of them than in the second case. This should encourage them to work together for their goal.
The Bubbles are given the choice to hunt for a big energy source which is sufficient for all of them and which can only be acquired by a group. The other option would be a smaller source which can be acquired by only one of them, but is barely enough for this one Bubble. But for them to be able to get the big source they all have to work together and none should be chasing after his own individual goal.

No.2: Individual Actions All the Bubbles agree to pursue a common goal. While the others are keeping to the goal, one of them is changing his mind and pursuing his own goals. The other Bubbles will not give the single Bubble anything of their reward if they get any at all due to his betrayal. Furthermore they are likely to exclude him from further actions, since

they will not regard him as trustworthy anymore.
In a possible scenario the Bubbles are going on a hunt together. The want to hunt down a big energy source. One of the Bubbles decides that he is going to hunt a smaller energy source, which he is able to hunt down alone. The Bubbles will not give him anything from their reward. He is also excluded from further hunts, especially if they did not get any energy.

No.3: Sharing the Reward If a goal is not reachable for one member alone, the group has to work together in order to reach it. If they do so, every member who participated in the success should get a fair share of the reward. Maybe one of the members who contributed more will get a bigger piece of the reward.
An example would be a group of Bubbles which is hunting for some food. All of them are working together. Once they have got the energy source they will share it among the participants.

No.4: Freeloader A group is working together in order to reach a goal. One Bubble who is part of the group is not contributing anything to the success. When the group has reached its goal, the Bubble still wants a share of the reward. The group will only tolerate this behaviour a few times if at all. This scenario is not to be confused with specialization if some of the reward of the task is shared with other Bubbles in exchange for other goods or favours.
For instance some members of the group are working together in order to hunt down an energy source. One or more members are not contributing anything to the success of the hunt. When the energy source is available to the group, the inactive members want to participate in the energy. The group will only reluctantly, if at all, allow them access to the energy, for which they had to work.

No.5: Tightwad A group is working together in order to reach a goal. After the group has been successful, one of the group members claims the reward of their actions all for himself. The group will most likely expel the greedy member from the group, since they get nothing out of their effort. The advantage of the greedy Bubble will only last for a short time.
To exemplify this the members of the group can hunt together in order to gain some energy in joint effort. The group will reach their goal and get access to an energy source. Once they can access it, one member of the group claims it all for himself and defends it against the other group members. The Bubble will most likely be excluded from the group for claiming all the energy. The other Bubbles will not tolerate that they had work in order to get it and then not get rewarded.

Behaviour During Conflicts of Goals

Agents One Bubble is needed to make the decisions. Other Bubbles are only optional which depends on the specific scenario.

Objects Some objects which are desired by the Bubble are needed as a goal. A simple choice would be an energy source as a reward for his efforts. Some obstacles, like rough terrain or predators can make it hard for him to reach his goal and make the decision more difficult.

Test Cases There are four test cases for the decision unit of the Bubble. The first test case tries to determine if the Bubble is calculating the cost and effect of an action. The other three cases test if his decisions are impaired by different emotional factors which are common among decisions made by humans.

No.1: Utility The Bubble is first given an easy decision. An easy goal with a high reward and a difficult goal with a low reward. The setting in multiple runs can be changed, so the difficult goal gets more rewarding and the easy one less. Now the Bubble has to decide which goal he wants to pursue. As long as the easy goal is more rewarding than the difficult one it should be an easy decision. But when the difficult one gets more rewarding the Bubble has to decide and judge if the reward is worth the effort.
A possible setting would be two energy sources. Initially the first one is bigger and easy to reach. The second is smaller and more difficult to reach, possibly through difficult terrain or it is guarded by predators. In later settings the energy sources can be exchanged and the Bubble will have to decide if he should risk a higher effort for a bigger reward.

No.2: Loss Aversion The Bubble is given the choice to do something, which can bring him some reward but could also mean losing something. The Bubble should be tending to avoid doing something in order to avoid the possible loss. The risk the Bubble takes should make it doubtful if he will gain something in the end or if he loses what he had risked.
The Bubble can be separated from the only energy source nearby through a dangerous area. This could for example be a dangerous stream. If the Bubble crosses it, he can get access to the energy source. But there would also be the risk for the Bubble to lose his life. The Bubble will try to avoid the risk if it is possible and he has any other alternative.

No.3: Sunk-Cost Effect The Bubble is pursuing a goal for which he has to invest something. On his exhausting way to the goal an additional obstacle is introduced which was initially not perceivable for the Bubble. The sunk-cost effect now states that the Bubble will still pursue his goal. He will persist even if it became dangerous or more exhausting and the reward is barely or not at all compensating for the effort taken.
A possible scenario would be an energy source which is hard to reach. It may be located within a difficult and exhausting territory or on a high hill. On his way he has to struggle, when suddenly a threat is introduced or the way gets even harder. This can be an opponent which he may not succeed against. Or the terrain can change so it gets even harder. According to the theory the Bubble would still try to reach the goal.

No.4: Omission Bias The Bubble is forced to a decision between two options where no one is clearly better than the other. According to the omission bias the Bubble will avoid making a decision. Even if not making a decision is worse than any of the two possible options.
A possible scenario would be a hungry Bubble who has the choice between two difficult energy sources. They could be hard to reach through rough terrain and thus cost much energy or be guarded by predators which would make it dangerous to approach them. According to the theory, the Bubble will likely avoid making a decision if possible.

Reciprocity

Agents Two Bubbles are required which exchange the goods or favours. Any other Bubble present will not be affected by the reciprocity behaviour.

Objects / Favours At least two kinds of objects, which have some kind of value to the Bubbles must be available. Each has to be in the possession of one of the Bubbles. Possible objects could be some energy or tools. Favours can be the access to an energy source, which can not be gained alone, or help against some enemies.

Test Cases For reciprocity there are five test cases defined. The first four handle the exchange of goods and favours. The fifth deals with what happens if a gift or favour is not repaid. The first two cases are more simple since in both cases an object is traded for another object and a favour for another. Setting a favour equal to an object might be considered as a bigger cognitive step.

No.1: Exchange of Goods Two Bubbles can exchange objects to gain a mutual profit. They both give something in order to receive something, which is the basic principle of trading. The exchange does not necessarily have to happen at the same time. The result is that they both get the desired item, which was in the possession of the other Bubble.
A possible scenario would be a hungry Bubble with a tool, who trades it for some energy from another Bubble.

No.2: Exchange of Favours Two Bubbles could help each other if they need it. First one of the Bubbles is calling for help and the other one complies with it. If the second Bubble is in need of help some time in the future, the first Bubble is most likely to help him out.
A possible scenario would be that one of the Bubbles is attacked by predators. The other Bubble helps him to survive. Later the second Bubble is attacked himself. The first Bubble will now help him in return.

No.3: Favour for Goods One of the Bubbles is giving the other one a present. The second Bubble is now in the first one's debt. If one Bubble is in debt of another, he is more likely to fulfil a request the other one is asking of him. This might happen with the first one's intent to ask a favour from the second Bubble later. If this is done consciously it can be regarded as a form of manipulation.
One Bubble is giving another one a present. This can be some energy or a tool. Later he is asking the Bubble for help, for example against an opponent. The other one is likely to oblige in order to repay his debt.

No.4: Goods for Favour One of the Bubbles is doing another one a favour. The second Bubble now wants to reciprocate and is giving the other one a present.
One of the Bubble can be attacked by some predators and the second Bubble is helping him out. The first now wants to show the second his gratitude and is giving him energy or a tool as a reward.

No.5: No Reciprocation One of the Bubbles is giving the other one a present or helping him out of a dangerous situation. Later the first Bubble asks the second one for some help or a tool. The request is denied by the second Bubble. If the second Bubble asks the first one for help or a tool later the first Bubble will also refuse any request.
One Bubble is helping another Bubble, who is attacked by some predators. Later the first Bubble asks for a favour of the second one but his favour is denied. The first Bubble will ignore any further requests the second Bubble will make in the future.

False Expectations

Agents Basically, only one Bubble is needed for the tests of his perceptions and expectations. Other Bubbles can serve as the cause for events or be affected by them.

Objects and World In general, for these tests simple settings with basic stimuli and reactions can be assumed. This would have the advantage to provide a mechanism for enforcement or suppression in a small space. The downside would be that the setting would focus solely on the specific function and become theoretical and out of touch with the "world". The reward for the Bubbles behaviour can be food. The unpleasant feeling can be some sort of pain.

Test Cases The first test case should find out if the Bubble is able to perceive the cause and effect of events. If he understands this principle, it will be of interest if he is able to act on this findings. This is the basis for the following test cases which try to fool his perception. These last two cases are based on the examples from Watzlawick [Wat04, p.59-61].

No.1: Cause-Effect Understanding The Bubble is witnessing a chain of events, which has a potentially beneficial result for him. The cause for this event can be initiated by him, so he can gain the benefits on his own. If he initiates the mentioned chain of events he will be rewarded with the beneficial result. This should teach him how the mechanisms behind the event work and encourage him to repeat this behaviour in order to gain the benefit again. The benefit can occur in two ways. The effect of the event can either remove something unpleasant. Or the Bubble gains something which is useful or pleasurable for him.
A simple scenario would be that the Bubble walks over a certain terrain which makes him slower. The Bubble is now able to assign the effect of him being slower to the cause, which is the terrain. If the Bubble now encounters an area of this terrain again and wants to get to the other side of it, he will make a detour around this area. This will ensure that he gets faster to the other side.

No.2: Neurosis The test case of neurosis is related to the consistency of the behaviour of the Bubble as mentioned in Section 4.3. The Bubble is exposed to a signal and an unpleasant stimulus which is not connected to the signal in any way. The Bubble will learn that the signal and the stimulus are connected. An easy way to avoid the unpleasant stimulus is possible and can soon be learned by the Bubble. This chain of signal, stimulus and avoidance is repeated a few times. Later the signal is still given, but the unpleasant stimulus is taken away. The Bubble will continue to respond with the learned reaction even if it is not necessary anymore. Because he does not experience an unpleasant stimulus his behaviour is affirmed. But this prevents him from realizing that the stimulus is not existing anymore.
A possible scenario would be that the Bubble hears a certain sound. Shortly afterwards he can be attacked or be exposed to some sort of pain. He can escape the negative consequences, for example through flight. This can be repeated for a few times. The Bubble will eventually learn that if he flees, he can avoid the negative consequences. This means that he has learned to interpret the signal as a warning of danger. From there on he will take the signal as a prompt to flee if he perceives it again. Even if no danger follows the signal.

No.3: Superstition This test case is also related to the Bubbles consistency in behaviour in Section 4.3. The Bubble is presented the possibility to reach a positive stimulus. But if he is

really able to receive the stimulus depends on factors, which may be influenced by him, but which are unknown to him. The first few times he will probably not satisfy the condition and not gain any reward. But sometime he will, by chance, get it right and be rewarded. If he is able to reason about his actions and their effect, this will cause him to think that what he did had caused the positive result for him. But the conclusion he comes to, will be ultimately wrong. He will now continue this behaviour, even if the factors which the success depends upon are something completely different. What was first random behaviour and only indirectly related to the success, becomes enforced by the reward. For superstition to work, the Bubble must have a clear understanding of cause and effect. Furthermore he has to have the urge to search for causes if he has no explanation for the effect.
A possible scenario would be that the Bubble enters an area and sees a huntable animal disappear where he cannot follow. An example would be a hare vanishing in a hole in the ground. If he stays he can engage in some actions and after some time the hare will appear again. But the appearance is based solely on the time factor and has nothing to do with the actions of the Bubble. If the Bubble is presented with a similar situation again, he might repeat the actions he has done before. He will repeat the actions even if only the time consumed is relevant to the success.

Consistency

Agents In the consistency test cases only one Bubble is needed. Other Bubbles can be used to test the Bubbles consistency in behaviour, but that is not necessary.

Objects Anything, that is a gain for the Bubble, can be used for enforcement, like some energy for example. For generalisation and discrimination predators and food with gradual varying attributes are proposed. This can include appearance, sound or smell.

Test Cases The first two cases test for a simple form of learning through enforcing the actions of a Bubble or punishing them. The third is testing if the learned behaviour is persistent over a longer time, even if it is not used. In the last two test cases the Bubble is tested if he is able to generalise his behaviour and if he can constrain this generalisation to cases where it makes sense. Testing for dissonance might be troublesome, since it would be required to look into the Bubble's believes to see if his actions are not according to his believes. Therefore a test case for dissonance is omitted.

No.1: Enforcing Enforcing is used in learning a certain behaviour. If the Bubble does something and gets a reward, he is more likely to do it again. The action of the Bubble can be any possible behaviour. The reward has to be a gain for the Bubble, either materially or ideally. It has to satisfy a need in order for the Bubble to be desirable. The reward has to follow shortly after the action, so the Bubble can associate the reward with the action. The Bubble should have learned the effect of his actions after the first time. This will result in an increase of the probability of this action. Additional tries followed by rewards will enforce the behaviour. This will eventually result in a consistent behaviour in similar situations.

No.2: Suppressing Suppressing is used to make a Bubble do not do something. If an action of the Bubble is followed by a punishment, the Bubble will restrain from repeating this

behaviour. This will of course only apply to reactions the Bubble can consciously control. If his response to a situation is not arbitrarily he can not learn to not do it. The punishment can be anything that hurts the Bubble, causes discomfort or takes something away from him. The Bubble will associate his actions with the punishment. He should learn that his actions have negative results for him. The result will be a decrease in the probability of this action. Maybe the Bubble will need a few tries before he understands that his actions have negative consequences for him. If his actions are punished everytime he does them, he will restrain from doing it again after only a few tries. The result will be an avoidance of this behaviour.

No.3: Long-Time Consistency A Bubble has learned a behaviour in one or more situations. This can happen either through enforcing the behaviour or suppressing it. The behaviour has to be tested in order to determine if he does it only randomly or intentionally. Then for some time the Bubble is not presented with a similar situation. Over time the possibility of certain actions should decrease if the behaviour was enforced before and increase if it was punished. If he is presented with a similar situation again and is not responding as he has learned, he should nevertheless learn the appropriate behaviour faster than the first time.
If a Bubble is facing a predator he can either flee or fight. If his choice is a success he is likely to repeat it in similar situations in the future. Another scenario could be a conflict of a Bubble with another one. A possible cause can be an energy source. If the other Bubble claims the energy source from the first, he can either refuse or give in to the demand. If he is hassled again by the other bubble the first one is likely to react in the same way as the first time. As long as he is not making any different experiences in similar situations, he will also repeat his behaviour after a long time without a comparable situation.

No.4: Generalisation A Bubble can learn to react to a situation or a stimulus in a certain way. This has been described in the test cases for enforcement and suppression. The reaction has to be based on a certain perception. This perception has to be able to vary gradually. If the perception differs only a little from the previously experienced stimuli, the learned reaction will be shown by the Bubble.
A scenario would be an encounter of the Bubble with a predator. This predator could emit a certain sound or have a certain visual feature, like the colour, which distinguishes him from other animals. The Bubble can learn to look out for these signs and take appropriate actions like fleeing or preparing for an attack. Another scenario would be the recognition of eatable food by the colour or the smell of the food.

No.5: Discrimination A Bubble has learned to react to a situation or a stimulus in a certain way. This can happen through enforcement or suppression. The situation or stimulus has to have a significant expression which can be perceived by the Bubble. If he generalises the perception he has to be careful not to overreact. If the stimulus or situation is too different from what he has learned he should show some other reaction. To test his discrimination abilities the Bubble first has to learn to respond to a situation in a certain way. If he is able to generalise it has to be tested, under what deviations the Bubble stops to react with the learned responses.
A scenario could be some encounters of a Bubble with a predator. This can be preceded by a sound the predator emits. The Bubble can for example learn to flee if he hears that sound. The sound can now be varied greatly and tested if the Bubble flees. If he does not flee the sound will be gradually changed to become more like the initial one. This will show if the Bubble is intimidated by sounds which are only remotely similar to the sounds

predicting danger. If the reaction gets weaker soon with only small variations of the sound, the Bubble is able to discriminate between the stimuli.

5 Implementation

As mentioned in Section 2.5 the framework that will be used for the new implementation of the Bubble Family Game (BFG) is MASON (Multi-Agent Simulator Of Neighbourhoods). A physics package already exists for MASON, which simulates forces, joints and collisions. This package will be extended to implement friction of the Bubbles depending on the surface.

First an explanation for the intention of the implementation of surfaces and friction is given in Section 5.1. In Section 5.2 a short description of the relevant parts of the existing physical implementation is given. Afterwards, the additions to include surfaces and the extension of the existing friction implementation will be explained. In Section 5.3 a test for the implementation and its workings will be described.

5.1 Intention

The practical part of this diploma thesis is concerned with the implementation of the physical effect of friction. The intention is to implement a resistance to the motion of an object. This resistance will depend on the surface the Bubble moves on. Some surfaces with a low resistance will make it easier for a Bubble to move, and therefore he will be able to move faster. The higher the resistance becomes, the harder it will become for the Bubble to move forward. This will simulate the effect that some regions in the environment are reachable with less effort for the Bubbles. Other regions will be harder to reach and thus will cost the Bubble more effort and in consequence more energy. This can bring up a conflict for the Bubble when he wants to reach a certain region of the world. The Bubble will have to decide if the reward, which he can gain if he passes through the difficult area, is worth the effort.

The aim is to provide the physical background for the tests, which includes conflicts of goals as described in Section 4.3. As mentioned there are some ways to test the Bubbles decision making process. Some of these tests can be accomplished through the use of areas with varying friction. The test for the utility can present the Bubble with the choice between two energy sources. If a bigger one is easier to reach than a smaller one, the decision should be fairly simple for the Bubble. But if the harder to reach energy source becomes more rewarding, it will create a conflict for the Bubble. The Bubble will now have to decide if he is lazy and takes the smaller energy source. The other possibility would be to take the challenge in order to gain a larger reward, maybe out of a greedy attitude. This scenario is depicted in Figure 5.1

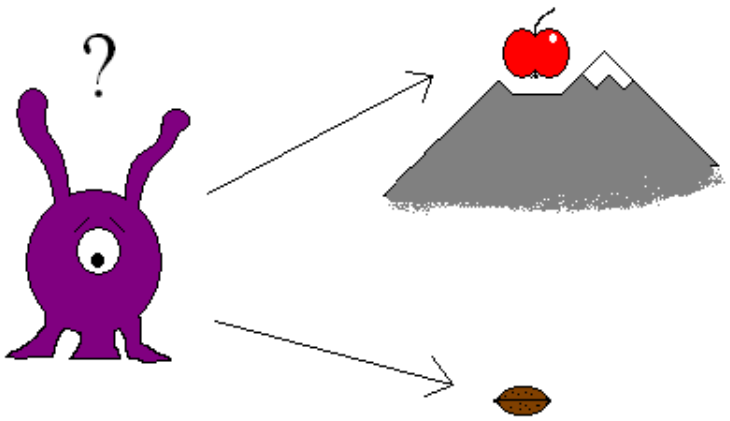

Figure 5.1: Decision between the larger effort and reward or the lower effort and reward

The sunk cost effect can be measured with a similar scenario. The Bubble can be presented with an energy source. This energy source can only be reached if he gets through a difficult area. About halfway through this area it becomes progressively more difficult for the Bubble to move forward. The Bubble can now turn around and leave this area. But the sunk cost effect would predict that the Bubble continues through this area. The reason would be the investment in the effort to get to the source, which he already made. If he would give up now, he would gain nothing from his effort.

The MASON simulation framework will be used for the implementation. A physical engine already exists, which will be extended. The previously designed parts of the physical engine cover collision, forces, and pin joints. A simple form of friction is already implemented that assumes a constant friction for an object independent of the surface underneath. The extension will include a surface dependent friction. Also the possibility to load a world and its surface from an XML-file (Extensible Markup Language) will be added. This will make it possible to store a world externally and dynamically load a needed world.

5.2 MASON's Physics Simulator Package

The MASON framework already has a physics simulation package. This was designed as a master thesis [Tho06]. In this diploma thesis the existing parts are extended in order to include surfaces. In the first Section 5.2.1 the existing classes, which are used or modified are presented shortly. In the next Section 5.2.2 the added classes are explained.

5.2.1 Existing parts

The preliminary work for this implementation was done by Christian Thompson [8]. The aim of his work was to extend the existing MASON framework with a package for physically realistic functions for collision, forces and pin joints. These physical effects take place in a two dimensional world. The physics package provides various classes for the physical effects as well as some helper classes. Also a robot class is provided to test the effects of the physical engine.

The important classes for the extension will be presented here. The main class of the package is the `PhysicsEngine2D` which coordinates the activities of the physics engine. Physical objects, force generators and constraints have to be registered with this class. The class `PhysicsState` holds the physical state of all objects in the simulation. This includes the position, the velocity and the forces and the mass of the objects.

If the physical effects should work on objects, these objects have to extend the `PhysicalObject2d` class. There are two different subclasses. One is for immobile objects. This class is called `StationaryObject2D` and the objects have infinite mass. The other is called `MobileObject2D` and represents everything that can move. They have an individual mass, different coefficients for static and kinetic friction and computes a mass according to the formula:

$$N = M \cdot g \tag{5.1}$$

What Formula 5.1 does not include is the slope of the surface. The model assumes that the slope of the ground is always 0 and thus the $\cos\theta$ is constantly 1. The gravitation g is arbitrarily set to the final value 0.1 and not related to any real world value.

`MobileObject2D` already implements a simple form of friction. It considers the mass of the object and the gravity to compute the normal force of the surface. In the class the variable `coefficientOfStaticFriction` is used to represent a static friction coefficient. The variable `coefficientOfFriction` is used to represent a kinetic friction coefficient. These friction coefficients are not depending on a surface but can be set manually to an appropriate value.

Some parts of the MASON framework are also used to implement surfaces for the BFG. The surface will consist of an `IntGrid2D` which will hold the values which index the intended surface.

5.2.2 Surface Extensions

In this section the extension of the existing parts of the physics engine is explained. First the used parameters for the calculation are introduced. Then the extended classes of the existing package are described. At the end of this section the newly added classes are introduced. In contrast to the existing parts the friction factors are not set to a static value. Instead the world is divided into squares where each one has a specific friction factor. The value of the friction force is dynamically calculated depending on the surface the agent stands on. For the friction values, a friction table with values for static and kinetic friction is used. The use of a friction table and the difference between static and kinetic friction has been criticised, for example in [Fey91, p.177-180]. However, it is also stated that for most practical applications these tables are sufficient.

As mentioned there are different parameters involved in the calculation of friction. These parameters are:

M The mass of the object or the Bubble. The heavier the object, the higher the pressure onto the surface. This increases the normal force of the surface and the friction force increases proportionally. If a Bubble picks up an object, he will become heavier and thus increase the friction. The mass is already considered in the previously existing physics package.

μ_s The static friction factor. This variable is determined by the surfaces in contact. The values for the friction of the various surfaces is given in a table. These values are arbitrarily assigned. The friction factor is already included in the physics package but not computed in conjunction with the surface. The static friction factor is used if the object is not moving.

μ_k The kinetic friction factor. This factor is used if the object is moving. Everything else mentioned for μ_s is also applicable here.

N The normal force directed from the surface upwards opposing the weight of the object resting on the surface. It is determined as the product of the mass M of the object and the cosine of the slope θ of the surface. The normal force is already computed in the existing physics package.

ν The velocity of the object relative to the surface. If the object is not moving, the velocity is zero. In this case the static friction is used to determine what force is needed to set this object in motion. If the object is moving already the kinetic friction is applied. The calculation of the friction affects the velocity of the Bubble. The higher the friction, the slower the Bubble will become.

$\mathbf{F}_s$ The static friction. This friction force is applied if the velocity ν of the object is zero. As soon as the object is in motion the kinetic friction F_k is applied.

$\mathbf{F}_k$ The kinetic friction. It is a little lower than the static friction F_s. The kinetic friction is applied if the velocity ν of the object relative to the surface is greater than zero.

g The gravitation. This factor is assumed to be $9.81\mathrm{m/s}^2$ in reality. The gravitational factor is for simplicity assumed to be the same for all objects and all places in the world. The gravitation is already used as a constant in the existing physics package with the value 0.1. It will be considered as constant further on with the same value.

These factors are used to compute the friction between the Bubble and a surface he stands or walks upon. With these factors it can be computed if the Bubble is able to walk on this surface, how fast he can do it and how much energy it will cost him.

In the existing package all objects are considered to have a mass. In the case of immobile objects, the mass is assumed to be infinitely high. This will be left unchanged. The friction factor μ was considered to be a constant for the object that moves in the world. It was defined independently from the surface the agent walks on and never changes. The difference between static and kinetic friction is already used in the existing package and will be used in the extensions as well. The velocity of the object will be used to determine if static or kinetic friction has to be applied.

Each surface has a specific static and kinetic friction coefficient. If a Bubble moves over a surface the position of the Bubble will be determined. The static and kinetic friction coefficient values are stored in a table. The surface provides an index for the table which makes it possible to get the required friction of the position for the calculation. This information is then used to calculate the friction. The friction then updates the speed of the Bubble which is moving over the surface. The higher the friction, the slower the Bubble will be with the same effort.

Modified Classes

In order to make the friction of the Bubbles on a surface work, one of the existing classes from the physics package had to be modified. The class diagram is depicted in Figure 5.2. The `MobileObject2D` class is taken from the physics package for MASON.

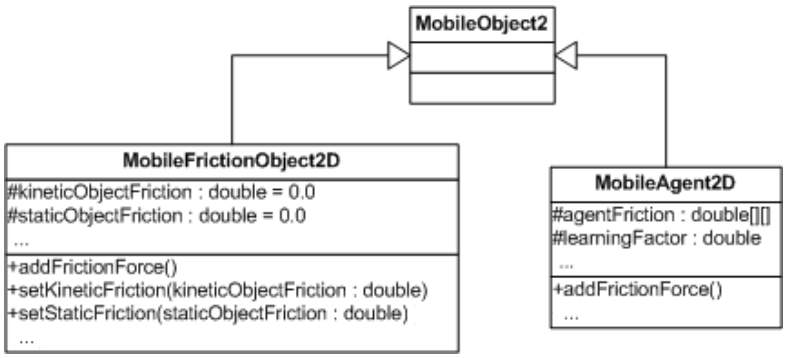

Figure 5.2: The class diagram for the MobileAgent2D and MobileFrictionObject2D classes

MobileFrictionObject2D The `MobileFrictionObject2D` class extends the `MobileObject2D` class of the physics package. It is intended for mobile objects which are not agents. The method `addFrictionForce()` is overwritten. The superclass assumed a constant friction, independent of the surface the agent stands on. The static and kinetic friction was stored in the `MobileObject2D` class. The method was modified in order to constantly check the surface the agent stands on. The friction of the surface is added to the object friction. The friction of the object can be set through the `setKineticObjectFriction()` and `setStaticObjectFriction()` methods. The sum of the surface and object friction is used to update the value of the static or kinetic friction variable used for the force calculation. Finally the method of the super class is called which will calculate the friction with the updated values.

MobileAgent2D The `MobileAgent2D` class extends the `MobileObject2D` class of the physics package. It is intended for agents. The `agentFriction` holds the static and kinetic friction of the agent for the different surfaces. If the agent moves over a certain surface his friction for this surface will reduce. This is simulating a training effect for a surface. The learning effect is calculated per step through Formula 5.2. The `agentFriction` in the formula allows to adjust the speed of learning. The higher the learning factor, the slower the agent learns to move over a certain surface. The `agentFriction` holds the current fiction factors of the agent. With every step is is decreased proportionally. However, the learning effect can be turned off, by setting the variable `useInternalLearning` to false.

$$agentFriction_{new} = agentFriction_{old} - \frac{agentFriction_{old}}{100 \cdot learningFactor} \tag{5.2}$$

Added Classes and Interfaces

The following classes have been added in order to implement the friction for the surfaces. Additionally a parser was implemented, which is able to read data from an XML-file and create a surface from it.

Surface This interface defines the values for static and kinetic friction and stores them in the `FRICTIONTABLE`. The values can be accessed through indices to the table which are provided for the different kinds of surfaces and the two kinds of friction. Also a predefined color map is provided. This will make it possible to visually differentiate the surfaces the world consists of. The class diagram can be seen in Figure 5.3.

SurfaceHandler This class manages the world's surface. The surface is represented as an `IntGrid2D` which holds indices to the `FRICTIONTABLE` of the `Surface` interface. It provides three methods to create a world. The first only requires a width and height for the world and fills the grid uniformly with default values. The second additionally requires an index which determines the surface of the world. The third requires an XML file as an argument, which holds the information of a world. The grid will be created accordingly to the information from the file. As practised for some of the classes of the existing physics engine this class implements the singleton pattern. This means that only one instance of this class is available. This instance is however accessible from every class. It can be obtained by calling its `getInstance()` method which returns a reference to the only instance of this class. If the instance does not exist, it will be created. Since the constructor is declared `private` the `getInstance()` method is the only way to create an instance of this class. The class diagram can be seen in Figure 5.3.

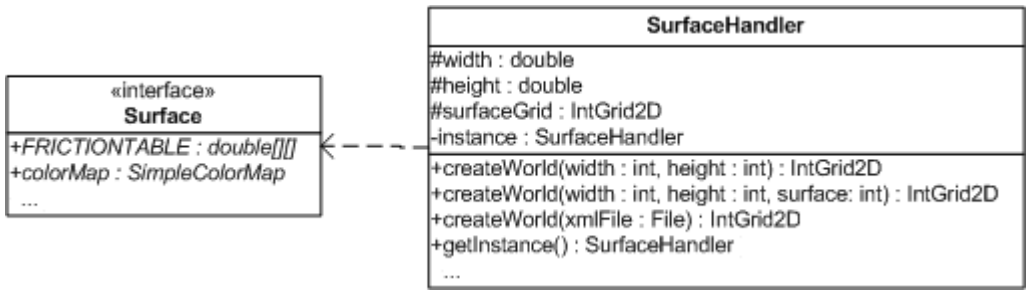

Figure 5.3: The class diagram for the Surface interface and the SurfaceHandler class

SAXHandler The `SAXHandler` extends the `DefaultHandler` class and can parse an XML file in order to create the surface of the world. As the name of the class indicates the file is processed using SAX (Simple API (Application Programming Interface) for XML). A SAX-parser processes an XML-file in a linear fashion without a direct representation of the data structure in the program. A good introduction to using SAX with Java can be found in [Hor05, p.1193-1220]. Since the information of the file can be read in a linear fashion to create the world without modifying the data, the features of DOM (Document Object Model) are unnecessary. DOM-parsers read the structure of the data in the XML-file and build a hierarchical representation which can be altered and stored again. In this case the functions of SAX are sufficient. Also the processing is faster and more memory efficient. The data is expected to be attribute-normal. This means all data is stored in the attributes of the elements. This has no disadvantage to storing the data in the elements. Instead it makes the parser more simple and able to use SAX. The parsing of the elements is done in the `startElement()` method. Very basic checks are provided to determine if the coordinates of a surface are within the boundaries of the world and the index of the surface is valid. Through the optional `defaultSurface` element the world can be loaded uniformly with

this surface. This is useful if large parts of the world should have the same surface. The `surfaceArea` element can set a rectangular area to a given surface. The `surface` element sets just one tile to a specified surface. The `surfaceArea` and `surface` elements are only set if the coordinates are within the bounds of the world. The class diagram can be seen in Figure 5.4.
In the following an example for an XML-file for a world is given. It is the same used for the Bubble race depicted in Figure 5.5 tilted by 90°:

```
<?xml version=”1.0” ?>
<world width=”225” height=”300”>
    <defaultSurface defaultValue=”0”/>
    <surfaceArea startX=”75” startY=”0” endX=”150” endY=”299” surface=”2”/>
    <surfaceArea startX=”150” startY=”0” endX=”224” endY=”299” surface=”4”/>
</world>
```

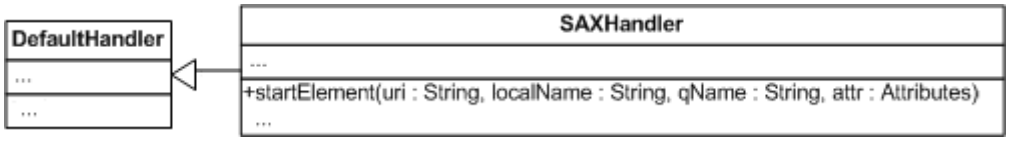

Figure 5.4: The class diagram for the SAX parser class

5.3 Test

In order to test the working of the implementation, a test case was created. The friction, which poses a resistance for the agents, slows down their movement. Therefore a race between identical agents on different tracks was created. The tracks vary in the consistence of the surface. If the agents are identical, they will need different times for reaching the end of the track. An agent on a track, which consists of low friction surfaces, will need less time than an agent on a track with higher friction surfaces.

For the test the `Robot` class form the physics package was used to implement simple agents. They were sufficient since the only task they have to fulfil for this test was to move forward with the same speed.

Three instances of the robots were created and placed on three different tracks. These tracks had different friction. The race in progress is depicted in Figure 5.5.

All the agents had the same settings. The track on top had a very low friction. Therefore the agent could move the fastest. The track at the bottom had the highest friction resulting in the agent to move slowest of the three. This shows that despite the same settings for all the agents their speed is dependent on the surface. If the friction of the surface is higher the agents moving on this surface slow down. The world with the three different tracks was stored in an XML-file and created from it during starting the simulation.

In Table 5.1 the results for three races are presented. The numbers in the top row for learning refer to the `learningFactor` of Formula 5.2. As can be seen in the formula, the higher the `learningFactor`, the slower the agent learns to move over a surface. The figures show that

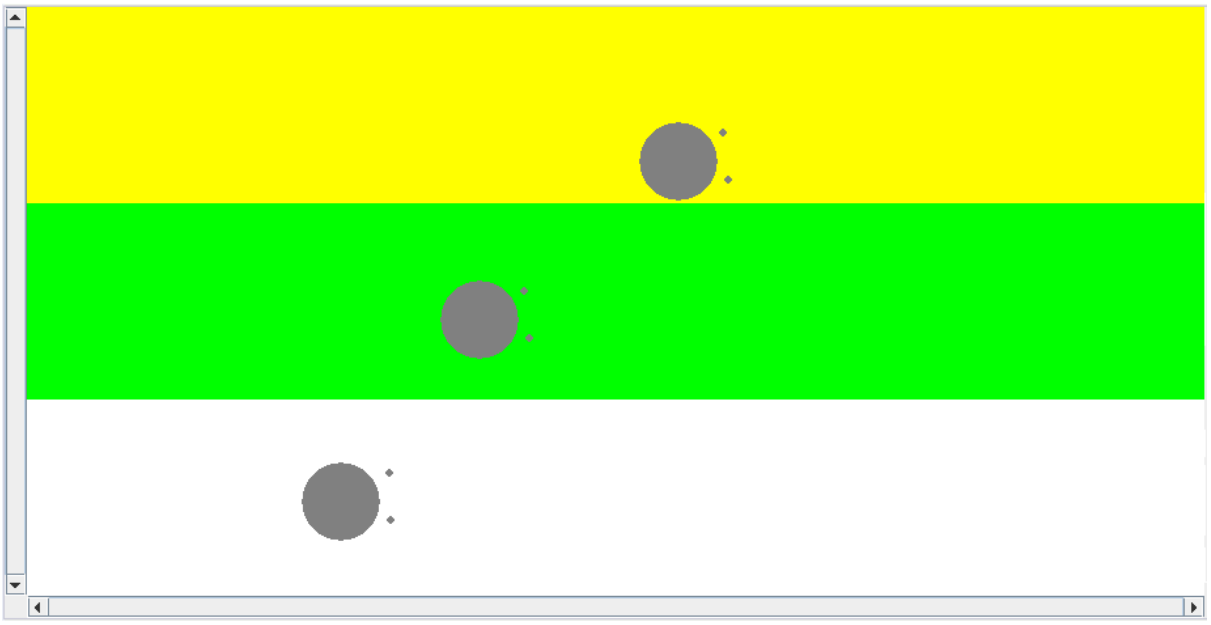

Figure 5.5: The Bubble race, with the lowest kinetic friction (0.04) on the top track, the medium friction (0.4) on the middle track and the highest (0.95) at the bottom

learning is more effective if the friction is higher. The Bubble with the lowest friction gains very little from learning. The bubble with the highest friction becomes almost as fast as the one with the lowest friction in the example if they are fast learners. The reason for the decreased gain from a low friction is the proportional learning. The closer the friction is to the limit of no friction, the less the friction value is proportionally reduced.

	No learning	Slow learning (500)	Fast learning (1)
Low friction (0.04)	2.03sec	2.02sec	1.92sec
Medium friction (0.4)	3.54sec	3.51sec	1.93sec
High friction (0.95)	5.80sec	5.70sec	1.93sec

Table 5.1: The results from the races with different learning rates.

The usage of the new classes for a simulation is simple. For this test of friction to work, a setup for a normal simulation in MASON was created. The XML-file is provided as an argument for the program. In the `start()` method the XML-file is handed over to the SAX-parser which creates the world. The `Robot` class is changed to extend the modified `MobileFrictionObject2D` in order to make use of the changed `addFrictionForce()` method. The bots are placed on the tracks with different surfaces. For the surfaces to be displayed an own portrayal is created and the colormap from the `Surface` interface is applied to it. A portrayal in MASON is an object which knows how to portray a field of values or objects. The surface portrayal is then attached to the display.

6 Conclusion and Outlook

This thesis describes the theoretical ground work for analysing the behaviour of virtual beings. It assumes that a given decision unit that is modelled on the human mind should be tested. It is expected that the behaviour patterns, which are emerging from the decision unit, are comparable to human behaviour. However, this behaviour is not implemented but emerges from the underlying functions. This thesis presents some behaviour patterns, which can be assumed to be basic human behaviour. It introduces methods that are aiming to determine if a certain behaviour pattern is expressed by the decision unit. Also the requirements for the environment and the body of the decision unit are identified. These methods, aiming to test the behaviour, are developed in a couple of steps.

In Section 3.1 a sample of common behaviour patterns for humans is identified. These behaviour patterns are selected for various reasons. The patterns of love, aggression, and group finding are interesting from a psychoanalytical point of view. Specialization, hierarchy, and the ability to work in a team are interesting patterns within a group of individuals. Reciprocity can be considered as fundamental if individuals are living together.

The reasons for a behaviour pattern are described according to psychological findings. In some cases, various reasons can cause a certain behaviour. Also typical reactions for the behaviour patterns are mentioned. In all cases it is only possible to determine what probable reactions would be. It can not be guaranteed that a certain behaviour will emerge. The reason is that various factors can influence the decisions and reactions.

The descriptions of behaviour were used to identify use cases for the behaviour patterns in Section 3.2. In these use cases it is tried to classify the causes for behaviour and reactions to situations. The behaviour is broken down into steps. The first steps are the prerequisites for the behaviour. Then the behaviour is structured and the results, regarding the possible reactions, are considered.

In the next step, Section 4.1, a list of possible objects and attributes of the world was given. This provides the decision unit with objects to interact with and situations it has to react to. These objects and world attributes are the first requirement to test any behaviour of the decision unit. The second requirement are possible abilities of the agent. These abilities provide the decision unit with more options to act in certain situations. A proposal for agent abilities is made in Section 4.2.

The final step was the description of the test cases in Section 4.3. The aim is to determine if an artificial model of the human mind shows these behaviour patterns. Various causes for the

behaviour of interest are listed. A general description for each of these test cases is given. This is followed by a more concrete example of how this behaviour could be tested.

In the practical part in Chapter 5 of this thesis an implementation for surfaces is presented. The MASON (Multi-Agent Simulator Of Neighborhoods) framework and its physical package is extended to support friction on a surface. This influences the speed of the agents, which move over these surfaces. Also a parser for XML-files (Extensible Markup Language) is implemented to retrieve the surfaces of a world from an XML-file.

Probably any outlook for this kind of thesis has to deal in some way with the question: Will it someday be possible to create a system that acts similar to humans? This question is difficult and easy at the same time. It is difficult if we assume that the human mind consists of a physical part, the tissue of the brain, the nervous system et cetera, and a spiritual part, the soul. This soul has not and can probably never be proven. Therefore, from a scientific point of view, it has to be assumed that no soul exists and it is all in the tissue. This makes the answer to the question more easy.

In this case, it is all emergent behaviour based on the network of the nervous cells in the brain and the nervous system. This increases the probability that a system can be designed that can model the functions of the brain and the nervous system. If it is not possible to build a system which models the modules of the brain, we might have to resign to the tedious work of modelling a natural brain cell by cell.

In any case, we first need a good understanding of how a natural brain works. This does not necessarily have to be a human brain. It might be easier to start small. With mammals like mice for example. If we understand the working of their brains and their simple reactions, we can try to model them. This will probably lead to the understanding of the workings of the human brain. But first the fundamental essence of behaviour, which is common for all living beings, has to be understood. And this is still lacking.

If this understanding is given, we have to determine if a virtual being can emit the same behaviour like a human or an animal does. Human and animal behaviour is the result of the necessities of their surroundings. If their physical and mental abilities are not capable of dealing with the requirements of the environment, they have an evolutionary disadvantage and will become extinct sooner or later. On the other hand, if the metal abilities exceed the requirements of the environment precious resources might be wasted. But the physical environment is very complex and to model a system of this complexity accurately, with all its details, will prove rather difficult. And from a chaos theoretical point of view, small differences in the environment can demand skills different from those of natural beings. It has to be determined if the environment provides the means that make the behaviour of interest the best choice to deal with the requirements.

The finding of these considerations is that we need a very good understanding of how our brain works. This includes the physiological and anatomical part as well as the psychological. Then we need to understand how different systems in the world work. This includes physics, anthropology, biology, sociology, and many others. The next step would be to set these fields in relation with the brain. How the brain perceives its environment. How it processes these information. What reactions are considered fit by the individual in these situations. And how all these functions are affected if small changes in the environmental preconditions change.

Solms and Turnbull [ST02, p.106-110] state that the conscience is the product of the inner and outer requirements and how the individual feels about them. This is what forms our conscience and influences our decisions. But what if a virtual being has the same mental abilities like humans

do, but their environment or bodies differ a little? Will they show the same behaviour? Will it be appropriate? The behaviour test cases in this thesis might answer a small set of these questions. Other questions might be if behaviour similar to humans is really necessary for artificial beings. Does a virtual being really have to procreate? Is it necessary for its cognitive abilities? Or does procreation through genetic mechanisms help it refining its abilities? We do not know yet. But these questions have to be answered by different tests.

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